

A TEM INVESTIGATION OF THE FINE-GRAINED MATRIX OF THE PARIS CM CHONDRITE. H. Leroux¹, P. Cuvillier¹, B. Zanda² and R. H. Hewins², ¹Unité Matériaux et Transformations, Université Lille 1 & CNRS, 59655 Villeneuve d'Ascq, France (hugues.leroux@univ-lille1.fr), ²Laboratoire de Minéralogie et Cosmochimie, MNHN & CNRS, 61 rue Buffon, 75005 Paris, France.

Introduction: The meteorite Paris is a recently classified CM2 chondrite. The meteorite appears less aqueously altered than other CM chondrites and has not experienced significant thermal metamorphism [1-3]. The low alteration index is evidenced by the abundance of metal in a number of regions of the meteorite. However other domains show clear signs of well developed aqueous alteration as evidenced by the presence of phyllosilicates, tochilinite-cronstedtite intergrowths and magnetite.

Here we present an analytical transmission electron microscopy (ATEM) study of the fine-grained matrix material extracted from both well preserved and aqueously altered areas. The results are used to document the earliest steps in the aqueous alteration sequence of CM matrices.

Methods: Fine-grained matrix regions more or less altered were selected by optical microscopy and scanning electron microscopy (SEM) using BSE images. The least altered domains contain metal, approximately 3%. In more altered domains, the metal is almost absent and the matrix displays regions of different average grey tones in the BSE images. Eight electron transparent sections were prepared for TEM by the focused ion beam (FIB) technique using an FEI Strata DB 235. The FIB sections were examined by ATEM with a FEI Tecnai G2-20 TWIN (LaB₆, 200 kV) equipped with an energy dispersive spectrometer (EDS). Scanning TEM (STEM) was used for acquiring EDS data for microanalysis.

Results: The TEM investigation confirms that the matrix of Paris is heterogeneous. In the following, we distinguish two main types of microstructures, depending on the degree of aqueous alteration.

Fresh areas. In fresh areas, the matrix appears to be constituted by an aggregate of amorphous silicate blocks, separated from one another by empty space (porosity). Their sizes range from 100 nm to 1 μm (Fig. 1). The amorphous silicates contain a large amount of small iron-sulfides (dominant Ni-poor and minor Ni-rich) and a few Fe-Ni metal inclusions. The composition of the amorphous silicate chunks is relatively homogeneous from one block to another, with an average close to the chondritic composition. We note, however, an enrichment of Si and a slight depletion in sulfur.

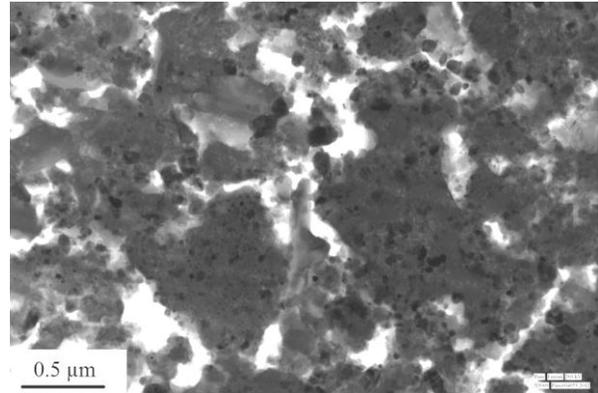


Fig. 1. Bright field TEM image of the matrix in a fresh area. The matrix is composed by amorphous silicates chunks separated one another by some porosity.

Moderately altered areas. Most samples show symptoms of moderate aqueous alteration. A fibrous morphology emerges more or less distinctly depending on the sample or areas in a given sample. There seems to be a continuous gradation from the amorphous phase described above to a well developed fibrous texture (Fig. 2). Electron diffraction patterns show that the fibrous domains remain substantially amorphous or have a very low degree of crystallinity which prevents a clear identification of the nature of phyllosilicates involved. The iron-sulfide inclusions are still present in areas where fibrous morphology is poorly established but they disappear as soon as the fibers become clearly perceptible. In these regions, the porosity is low or absent.

The compositions of the fine-grained phyllosilicates extend within the triangle defined by the cronstedtite-chrysotile-greenalite solid solutions. The ratio $\text{Mg}/(\text{Mg}+\text{Fe})$ remains low and displays a clear evolution as a function of the morphology, from 0.4 in areas almost fully amorphous to 0.25 where the fibers are clearly distinguishable.

In a number of occurrences, large crystals of cronstedtite frequently replace the fibrous morphology. They form more or less elongated slats, often with layers of tochilinite intergrowth. The average $\text{Mg}/(\text{Mg}+\text{Fe})$ ratio of the lath-shaped cronstedtite is close to 0.25. Some of the regions containing this coarse-grained cronstedtite have a high porosity.

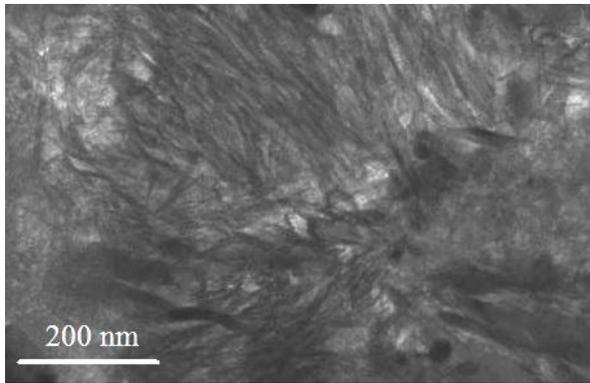


Fig. 2. Bright field TEM image of the matrix showing a fibrous morphology replacing the amorphous phase.

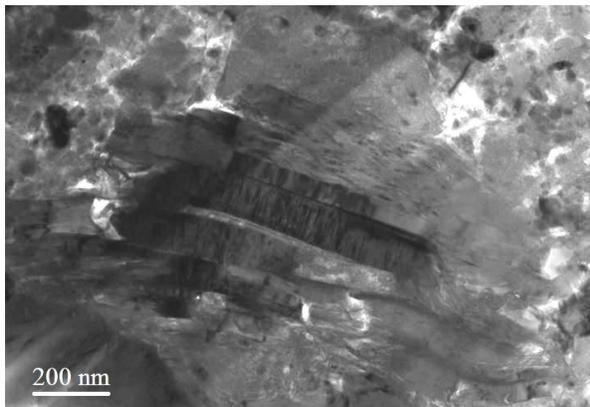


Fig. 3: Bright field TEM image showing cronstedtite laths with tochilinite intercalation.

Anhydrous silicates and carbonaceous material. All the samples studied (altered or not) contain anhydrous silicates and carbonaceous matter. The anhydrous silicates are forsterite and enstatite sub-micrometric grains. No composition gradients were found at the edge of the grains. The forsterite grains are usually rounded and free of internal defects or inclusions. The enstatite grains contains a large density of planar defects on (100) corresponding to ortho-clinopyroxene inversion. Several grains were found to be elongated along the [100] direction. In some altered samples, enstatite grains are partially replaced by an Fe-rich fibrous material at their edges. Carbonaceous material is located between the silicates components. A significant number of nanoglobules were observed. These organic globules, typically a few hundreds nanometers in size, are amorphous, spherical and frequently hollow.

Discussion: The CM chondrites display various degrees of aqueous alteration, from the moderately altered CM2 to the highly altered CM1 chondrites. From a mineralogical point of view, several studies

have described a mineral evolution and changes in compositions, depending on the intensity of aqueous alteration within the CM2 chondrites [e.g., 4-6]. According to this sequence, the Paris meteorite clearly displays a low degree of alteration. Indeed, phyllosilicates, when present, are Fe-rich. This shows that Mg-silicates have not been altered, as evidenced by the presence of numerous sub-micrometric grains of forsterite and low-calcium pyroxene well preserved in all the samples studied. The Fe-rich content of the phyllosilicates is probably a consequence of the alteration of metal and iron sulfides which are much more sensitive to alteration. If a fluid circulated in the meteorite, it would have been Fe-rich. The gradation of the phyllosilicate morphology is associated with a gradation of the Fe-content and certainly reflects a maturation of phyllosilicates.

In the less altered domains, phyllosilicates are absent. The silicates are amorphous and contain numerous inclusions of iron-sulfides and sometimes metal. This microstructure compares well to that of the GEMS found in IDPs [7] or with matrix of the primitive carbonaceous chondrites Acfer 094 [8], the CR QUE99177 and MET 00426 [9]. The average elemental ratios Mg/Si, Fe/Si and S/Si are close to those of GEMS, although with a slight iron excess. It also appears that compositions of the amorphous silicates are fairly homogeneous in contrast with the large compositional variation of GEMS. The Fe content and the relative homogeneity of composition is certainly the result of an exposition to a fluid rich in iron during the first stage of alteration on the parent body. The Paris meteorite is therefore a weakly altered CM which will allow us to specify the details of first stages of evolution of the fine-grained components on a CM parent body.

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