

**TEM INVESTIGATION OF FINE-GRAINED COMPONENTS IN THE MATRIX OF THE BISHUNPUR (LL3.1) CHONDRITE.** H. Leroux<sup>1</sup>, <sup>1</sup>Unité Matériaux et Transformations, Université Lille 1, 59655 Villeneuve d'Ascq, France (hugues.leroux@univ-lille1.fr).

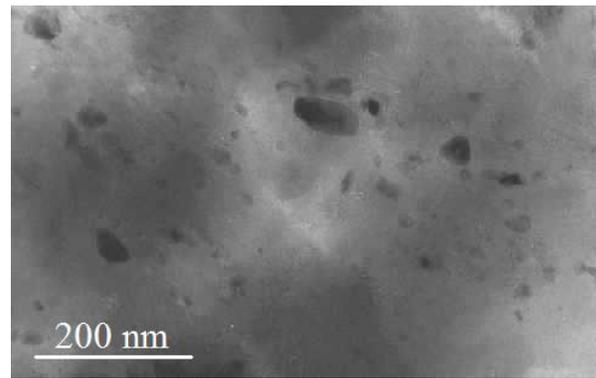
**Introduction:** Chondrites mainly consist of chondrules and a fine-grained matrix. The most primitive of them (close to petrographic type 3.0) escaped secondary processes such as aqueous alteration and thermal metamorphism on their parent bodies. The constituents of fine-grained matrices must have then retained signatures of the proto-planetary disk, prior to asteroidal accretion. Their study should provide an access to processes or primary characteristics of nebular dust. Phases constituting these matrices are submicrometric, so only the transmission electron microscopy (TEM) allows a detailed study. Because of the small grain size and the high porosity, matrices are very sensitive to aqueous and thermal alteration. Consequently, the number of chondrites that preserve the original character of primitiveness are rare [e.g., 1]. These matrices are composed of a complex assemblage of un-equilibrated phases, including amorphous and crystalline silicates, sulfides, oxides and carbonaceous material [e.g., 2-4]. Presolar grains are abundant, including silicates [e.g., 5].

In this study we have characterized by TEM phase components in the matrix of the Bishunpur LL3.1 ordinary chondrite. This meteorite is one of the least altered ordinary chondrites. Compared to Semarkona, aqueous alteration is weak and the peak temperature probably not exceeded 250°C [6]

**Experimental:** Several samples from the Bishunpur matrix were thinned by argon milling with a Gatan duo beam until electron transparency. The analytical TEM study was performed using a Philips CM30 (LaB6 filament) operating at 300 kV and a Tecnai G2-20 twin (LaB6 filament) operating at 200 kV. Microstructural analysis was carried out using conventional bright and dark field imaging. Structural informations were obtained using electron diffraction. Chemical compositions were measured using energy dispersive X-ray spectroscopy (EDS) with a Thermo Noran Si-detector (CM30) and an EDAX Si-detector (Tecnai). Chemical X-ray intensity distributions of elements were obtained on areas of interest. Details about the analytical procedure can be found in [7].

**Results:** The Bishunpur matrix consists of fine-grained material. The microstructure is somewhat variable from one area to another. Some domains are mainly composed by amorphous grains while in some others crystalline silicates are dominant. In both cases, the matrix contains numerous small metal and sulfide grains.

*Amorphous material.* Amorphous material (Fig. 1) is frequent and has a broad range of composition. Most frequently it is rich in SiO<sub>2</sub> and FeO, on average. Some areas are close to the SiO<sub>2</sub> pole with only other minor elements (Mg, Fe, Al, Na). Some compositions are in good agreement with the average value of compositions of GEMS in IDPs [8]. Other areas containing amorphous material are rich in Al, Ca and Na, as previously mentioned in [6]. No clear boundaries can be evidenced between these different amorphous areas. Locally the amorphous material is replaced by phyllosilicates showing that aqueous alteration occurred in Bishunpur at low extent.

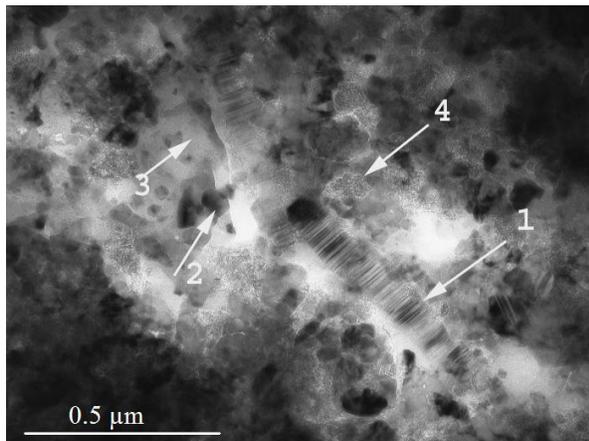


**Fig. 1:** Bright field image of a region of amorphous material. A large number of metal and sulfide inclusions are present (dark dots).

*Metal and sulfides.* The amorphous silicate material contains a large number of metal and sulfide inclusions (Fig. 1). The metal grains usually have an irregular shape and a size ranging from a few nm to several hundreds of nm. These metal grains are kamacite (~ 4 at% Ni) and taenite (~ 52 at% Ni) in approximate equal proportion. The sulfide grains are generally smaller than the metal grains, typically a few tens of nanometers. They are Fe-rich for most of them, although some are rich in Ni. It is important to note that the metal phases and sulfide phases are generally not in close association. Most of them correspond to isolated grains embedded in the amorphous matrix. In SiO<sub>2</sub>-rich areas or within areas converted to phyllosilicates these metal and sulfide inclusions are not present. In this latter case, they were probably dissolved by aqueous alteration.

*Crystalline silicates.* Numbers of areas are dominated by crystalline silicates, mainly olivine and pyrox-

ene (Fig.2). Frequently the composition of pyroxenes is close to enstatite. Some grains are elongated along the [100] direction containing a striated microstructure along (100) planes which corresponds to alternating ortho- and clino enstatite lamellae. The size and morphology of these grains is comparable to enstatite whiskers frequently encountered in CP-IDPs [9]. Olivine grains have a broad range of composition with a peak around  $Fa_{40}$ - $Fa_{55}$ . Their size is typically 100 nm diameter on average but smaller grains are frequent. Some larger grains are also present. In some cases, they have a forsteritic core surrounded by fayalite-rich rim. The Mg-Fe zonation length is lower than 0.5  $\mu\text{m}$ . In other cases, larger grains, up to several  $\mu\text{m}$ , are found with a composition strongly enriched into fayalite, typically  $Fa_{95}$ . They contain numerous voids. In these crystalline regions, the amorphous phase, found as an interstitial groundmass cementing the crystals, is frequently rich in  $\text{SiO}_2$ .



**Fig. 2:** Bright field image of a complex assemblage of amorphous and crystalline materials. It contains the dominant following phases (1) enstatite whiskers (2) amorphous material (3) olivine grains (4) carbonaceous material at the interstices between the silicates grains.

**Carbonaceous material.** Poorly crystallized carbon-rich material occurs within interstitial spaces between the amorphous and crystalline silicates. A few carbon globules are found, comparable to those described in several carbonaceous chondrites [e.g., 10].

**Discussion:** Our TEM study of samples from the matrix of the Bishunpur chondrite revealed a complex and heterogeneous microstructure. The presence of phyllosilicates shows that the meteorite has not escaped aqueous alteration. However this effect is local, many regions do not seem to have suffered from this alteration. Thermal-induced modification probably also occurred. The crystalline regions appear to be caused by

recrystallization of the amorphous phase. Indeed, in a given region, the olivine crystals have sizes and compositions fairly homogeneous within a given area. Concentration gradients detected in the large grains of olivine, with a forsterite-rich core and a fayalite-rich rim, demonstrate reactivity with the local environment. In these crystalline areas, the residual amorphous phase enriched in  $\text{SiO}_2$  can be reasonably explained by the crystallization of these olivines. The matrix still retains many amorphous regions with well preserved metal and sulfides nanograins that appear unaffected by secondary processes. The amorphous phases have variable compositions depending on the studied region. This chemical variability is also present for GEMS of IDPs [8]. One possible interpretation, as developed by [8] for the GEMS grains, would be a non-equilibrium formation from reservoir having different compositions, thus limited sizes. The formation timescale prevented chemical homogenization or exchanges with the local environment. This is compatible with a brief thermal event and a formation by condensation at relatively low temperature which prevented the formation of crystalline silicates or self-annealing of the amorphous phase. The presence of sulfide embedded in the amorphous groundmass also argues for a relatively temperature process. This brief event could be contemporary to the formation of chondrules but a lower gas pressure, so that the liquid phase was not formed.

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