**ATEM INVESTIGATION OF AN AGGLOMERATIC CHONDRULE IN THE BISHUNPUR LL3.15 CHONDRITE.** G. Bellino[1], H. Leroux[1] and M. Roskosz[1] [1]Unité Matériaux et Transformations, Université Lille 1 & CNRS, F-59655 Villeneuve d'Ascq, France (guillaume.bellino@ed.univ-lille1.fr).

**Introduction:** Chondrules are submillimeter spheres composed mainly of ferromagnesian silicates. They are abundant constituents of most primitive chondritic meteorites [1]. Their textures suggest that they formed by the crystallization of a melted or partially melted material in the early solar nebula [1,2]. Some chondrules show little evidence of melting and may have formed by sintering of dust agglomerates. They have been termed "agglomeratic chondrules" [3,4]. These chondrules have sizes similar to typical chondrules but differ from them in being fine-grained [3,4,5]. Such objects may have preserved some properties of the precursors and give us a good opportunity to better understand the nature of the dusty environment of the solar nebula during chondrule formation. Here we present a study of such a chondrule in the Bishunpur LL3.15 ordinary chondrite by analytical transmission microscopy (ATEM). The aim of our work is to better understand the early evolution of the dusty precursors during chondrule formation.

**Sample and methods:** The chondrule was selected from a polished section of the Bishunpur LL3.15 ordinary chondrite by using backscattered electron (BSE) imaging on a HITACHI S4700 scanning electron microscope (SEM). FIB electron transparent sections (~100 nm thick) were extracted using an FEI Strata DB 235 at IEMN (University of Lille, France). ATEM studies were performed using a FEI Tecnai G2-20 and a Philips CM30, operating at 200 and 300 kV respectively, at the electron microscopy center of the University of Lille, France. Microanalyses were obtained using an energy dispersive X-ray spectrometer (EDS).

**Results:** SEM studies show that the chondrule is dominated by a mixture of fine-grained (<5-10 µm across) Fe-rich olivine ($Fa_{40}$ on average) and troilite. Troilite is found preferentially at the periphery of the chondrule and forms a continuous network between silicates. The chondrule displays a grain size variation with extremely fine grains at the periphery and coarser grains in the inner region (Fig. 1). Our study focuses on the fine-grained fractions (frequently < 1 µm) in order to determine the composition and the texture at the sub-micrometer scale. FIB sections were extracted from these areas that can not be fully investigated by SEM.

ATEM studies revealed that the fine-grained areas of the chondrule can be subdivided into three categories with respect to their grain sizes and textures (Fig. 2): matrix-like material (MM), very fine-grained material (VFM) and fine-grained material (FM). Although the chondrule shows areas with different compositions, its bulk composition is close to the chondritic value .

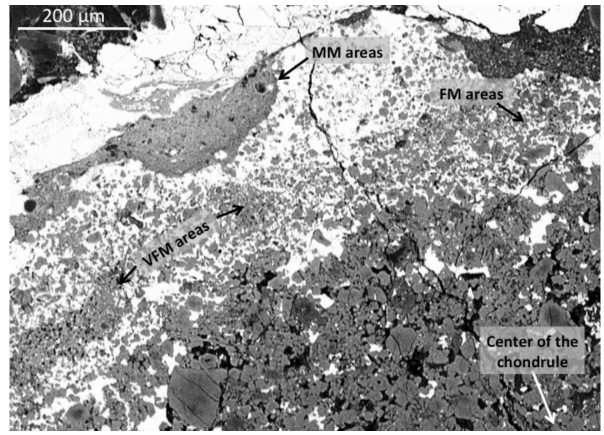


*Fig 1. BSE-SEM image showing the grain size variation of the chondrule. MM areas are located at the periphery of the chondrule in the troilite rich area. The grain size increases from the periphery (MM areas) to the inner region.*

MM areas are located in the troilite rich area (Fig. 1). They form lenses up to 60-100 µm wide. They are composed of very fine-grained (< 100 nm) materials, dominated by anhedral Fe-rich olivines with feldspathic glassy regions (Fig. 2a). The average composition of MM areas is enriched in Fe and depleted in S when compared to solar values (Fig. 3).

VFM areas are coarser than MM areas and consist of a mixture of grains with different sizes (Fig. 2b). They are composed of small (100 to 500 nm across) anhedral to subhedral Fe-rich olivine ($Fa_{45}$ on average), Fe-Ni metal and Fe-sulfide inclusions within a feldspathic glass. The average composition of VFM areas is close to the solar value except for Si and S which are enriched and depleted relative to the chondritic composition respectively (Fig. 3).

FM areas with coarser grains consist of an intimate mixture of sulfides and/or metals with silicates (Fig. 2c). There is no feldspathic glass in these areas and olivines show well equilibrated 120° triple junctions. The average composition of FM areas are also close the solar value but they are depleted in S and slightly depleted in Fe (Fig. 3).

For all areas, large Mg-rich olivine grains (> 500 nm) are present. They show chemical zonation with Mg-rich cores and Fe-rich edges. They also contain crystal defects (mostly dislocations), unlike the small Fe-rich olivine grains of all areas.

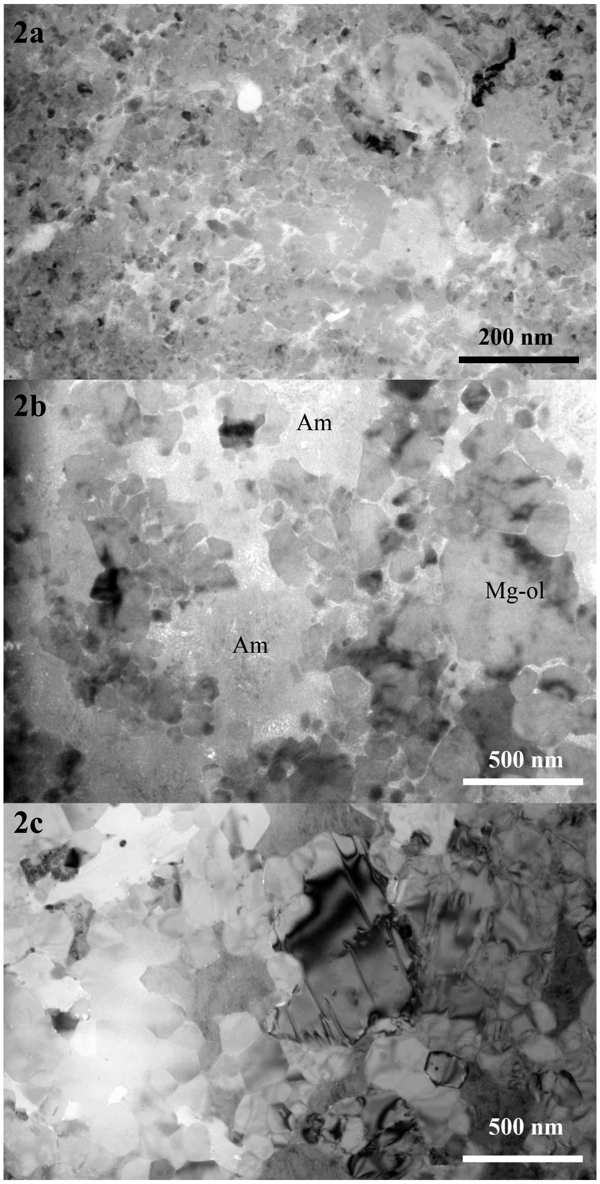


*Fig 2. TEM bright field images (a) The matrix-like material (MM) is dominated by very fine-grained (<200 nm) anhedral Fe-rich olivine; (b) The very fine-grained material (VFM) consists of small anhedral to subhedral Fe-rich olivines and large subhedral to euhedral Mg-rich olivines (Mg-ol) embedded in an amorphous feldspathic material (Am); (c) The fine-grained material (FM) consists of a mixture of olivine and sulfide grains.*

**Discussion:** The characteristics at the submicron scale of the fine-grained fraction of an agglomeratic chondrule have been investigated by ATEM for the first time. We have identified variations in grain size and texture from MM to FM areas. They are interpreted to reflect progressive heating of dust precursor of quasi chondritic composition during the first steps of the chondrule formation. The identified variations correspond to grain coarsening during the heating in the sequence MM-VFM-FM and partial loss of S and Fe, from a dusty chondritic precursor. Although VFM areas show large feldspathic glassy regions, apparent partition coefficient for olivine are not comparable to those determined experimentally or measured in porphyric chondrules [6]. This indicates that temperature was sufficient to initiate melting but not enough to equilibrate olivine and feldspathic regions. This also indicates that olivine does not crystallize from a melt but likely formed by sub-solidus crystallization. This is consistent with the texture of MM and VFM areas and the shape of olivine in these areas. The small grain size of the chondrule, together with its chondritic bulk composition, indicates that olivine formed during sintering of quasi-chondritic dust agglomerates. Large magnesian olivine grains with chemical zonation and crystals defects are interpreted to be relict grains from Type I chondrules. Our study of the fine-grained fraction indicates that the chondrule is transitional to porphyric chondrules and may represent an intermediate state between porphyric chondrules and the fine-grained interchondrule matrix.

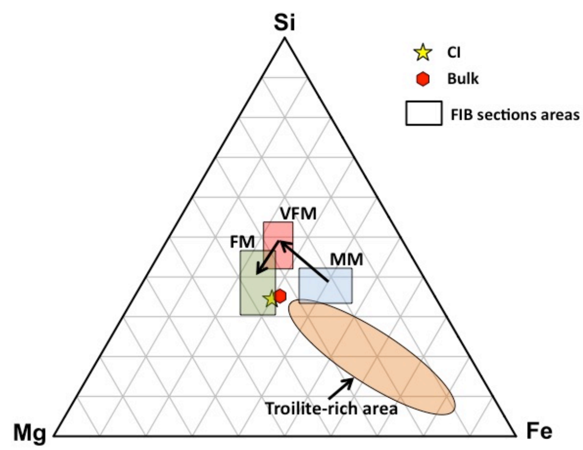


*Fig 3. Si-Mg-Fe ternary diagram showing compositions of the fine-grained (<1 µm across) studied areas (MM, VFM and FM). Black arrows show the sequence of the first steps of the chondrule formation. Solar composition (CI) and average composition of the chondrule (Bulk) are also represented. Data are given in % atomic.*

**References:** [1] Hewins R. H. (1997) *Annu. Rev. Earth Planet. Sci, 25,* 61-83. [2] Grossman J. N. and Wasson J. T. (1982) *GCA, 46*, 1081-1099. [3] Weisberg M. K. and Prinz M. (1996) *in Chondrules and Protoplanetary Disk,* 119-128. [4] Ruzicka A. et al. (2012) *GCA, 76,* 103-124. [5] Bellino et al. (2014) 77th *Annual Meeting of the Meteoritical Society, Abstract #5283.* [6] Jones R. H. (1994) *GCA, 58*, 5325-5340.