MINERALOGY AND PETROGRAPHY OF A SPECTACULAR REFRACTORY INCLUSION THAT UNDERWENT CHONDRULE FORMATION. J. Aléon[1] and M. Bourot-Denise[2]. [1]Centre de Spectrométrie Nucléaire et de Spectrométrie de Masse, Bat 104, 91405 Orsay campus, France, jerome.aleon@csnsm.in2p3.fr [2]Museum National d'Histoire Naturelle, 61 rue Buffon, 75005 Paris, France.

Introduction: Compound objects from carbonaceous chondrites composed of at least one Calcium-Aluminum-rich Inclusion (CAI), that is CAI-CAI compound objects or CAI-Chondrule compound objects are extremely useful to study the geochemical reservoirs of the earliest protosolar nebula, to decipher their spatial and temporal interactions and to study the mechanisms of CAI and chondrule formation [e.g. 1,2]. However such objects are rare even in the most primitive chondrites. In order to perform a detailed mineralogical, petrological and isotopic study of compound refractory inclusions, we systematically examined sections of the reduced CV3 chondrites Leoville and Efremovka at the Museum National d'Histoire Naturelle in Paris and prepared two new polished sections of Efremovka (sections 2005-08 and 2005-09). Here we report the discovery of E-MNHN-002, an object consisting of a CAI core surrounded by layers of material having affinities with type I porphyritic olivine-pyroxene (POP) chondrules.

Analytical techniques : E-MNHN-002 has been found in the two new Efremovka sections but is fragmented and incomplete in the 2005-08 section. Thus, most of the results presented here come from the 2005-09 section. The mineralogy and petrography of E-MNHN-002 were studied by Scanning Electron Microscopy (SEM), Field-Emission Gun SEM (FEG-SEM) and Electron Probe MicroAnalysis (EPMA) using the SEMs of the Laboratoire de Géologie at Orsay and of the Museum and the FEG-SEM facility at the University of Paris-Jussieu and using the Cameca SX100 electron probe of the CAMPARIS facility at the University of Paris-Jussieu.

Results : E-MNHN-002 is a ~ 3.2 × 1.8 mm elongated amoeboid shaped object. It is composed of five concentric layers, the two innermost layers (layers 1 and 2) being made of CAI material and the three outermost layers being made of material akin to type I POP chondrule (layers 3 to 5). Around ~20% of the inclusion, the outer chondrule-type layers are lacking. Coarser-grained textures are found in the CAI core in this area. In the following, mineralogy and petrography of E-MNHN-002 are described layer by layer starting from the inner core of the CAI.

Layer 1 : Inner CAI layer. The core of the CAI is composed primarily of fine-grained Al-rich forsteritic olivine, spinel, almost pure anorthite and Al-Ti-rich clinopyroxene (cpx). Grain sizes are typically 1-10 µm although cpx can be coarser-grained. Olivine and cpx are often associated and surrounded by anorthite. Spinel is systematically included inside anorthite. This mineralogical assemblage is typical of Amoeboid Olivine Aggregates (AOA) [3]. However, the textures are unusual for an AOA [3]. Here, olivines are often anhedral and show embayments suggestive of dissolution at contact with anorthite. Replacement of olivine by orthopyroxene (opx) is observed locally. Boundaries of large cpx grains often show intergrown cpx with euhedral anorthite laths. Exsolution of opx is commonly observed inside the cpx. Nano-inclusions of Cr-spinel are sometimes found aligned in forsterite, which is also suggestive of exsolution. These inclusions may account for the high Al content of olivine (up to 3wt% Al_2O_3). These observations suggest that the CAI core consist of an AOA that underwent partial melting and recrystallization.

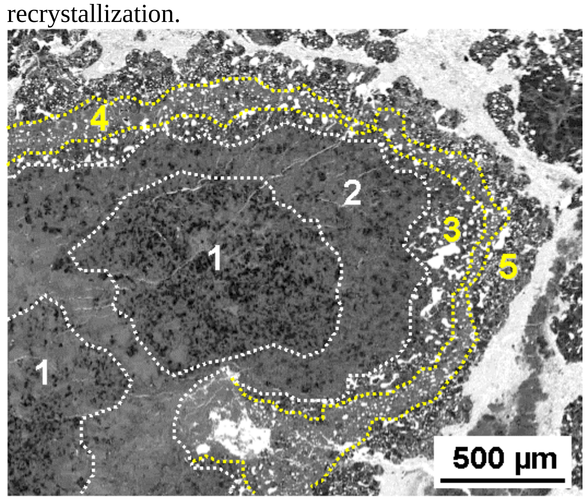

Fig. 1. Backscattered Electron Image of a portion of E-MNHN-002. Compositional layers are outlined (white : CAI layers 1 & 2, yellow : chondrule-type layers 3 to 5).

Layer 2 : Outer CAI layer. This layer is composed of the same minerals than the CAI core, however their relative abundances are different. Whereas olivine and spinel are abundant in the core they are minor in layer 2 and show extensive evidence of dissolution. Spinels are corroded, and often consists of µm-sized relicts in anorthite, olivines are rounded isolated crystals, some of which contain rounded inclusions of cpx. Most of layer 2 consists of cpx with lower Al_2O_3 and TiO_2 content than in layer 1 finely intergrown with anorthite.

Layer 3 : Inner chondrule type layer. Layer 3 is essentially a veneer of olivine and metal grains having strong similarities with the cores of type I POP chondrules. Olivines are rounded and chemically zoned with edges enriched in FeO. They are chemically identical to those found in chondrules from CV3 chondrites (5-8 wt% FeO, 0.2 wt% CaO and almost no Al_2O_3, MnO and Cr_2O_3). They rarely contain rounded inclusions of opx. Metal grains are often enclosed in or attached to olivine. Olivine and metal are cemented by a matrix of cpx and plagioclase.

Layer 4 : Intermediate chondrule type layer. This layer consists dominantly of Al-rich diopsidic/augitic cpx with metal inclusions, rare olivine showning abundant evidence of dissolution and interstitial plagioclase similar to that observed in chondrule mesostases (An content typically between 75 and 85 mol%). Minute euhedral silica crystals are observed in pockets with textures of a residual glass.

Layer 5 : Outer chondrule type layer. This layer is analogous to the outermost parts of type I POP chondrules. The major mineral is low Ca pyroxene with Al- and Ca- content that decrease down to those of pure opx. It contains inclusions of metal and small rounded inclusions of olivine. Minor minerals are interstitial Al-rich cpx associated to plagioclase (An content down to 65 mol%) and possibly glass. Plagioclase/glass disappears towards the outermost part of the layer which consists of co-crystallized cpx and opx with rare minute olivine relict inclusions.

Secondary alteration. Several evidences of secondary alteration attributable to parent-body metamorphism or metasomatism are found throughout E-MNHN-002 : (1) increase in FeO content in olivine from ~1 up to 17 wt% from the inside towards the outside, (2) replacement of anorthite by nepheline in the outer layer 2 and at grain boundaries in layer 3 to 5, (3) presence of hedenbergite locally in areas with textures of devitrified glasses, (4) oxidation of metal accompanied with edge crystallization of phosphates and exsolution of sub-µm chromite grains, (5) rare occurrence of carbonate.

Discussion : Olivine is found throughout the inclusion and systematically shows evidence of dissolution. By contrast pyroxene and plagioclase show a continuous chemical evolution from layer 1 to 5, respectively an increase in SiO_2 content (associated with a decrease in Al_2O3 and TiO2) and an increase in NaO. They also have textures indicative of crystallization from a melt. This suggests that E-MNHN-002 formed by partial melting of a precursor rich in olivine followed by enrichment of the melt in SiO_2 and alkalis during crystallization. The presence of two distinct olivine populations (based on chemical compositions) observed in the AOA and the chondrule-type mantle (respectively refractory forsterite and chondrule-like olivine associated with metal) suggests that the precursor was a compound object composed of an AOA core and a ferromagnesian mantle. The concentric layering indicates that the typical zoning of type I POP chondrule seen in layers 3 to 5 (olivine-rich core and opx rich exterior; the intermediate layer being crystallized from a melt possibly analogous to a chondrule mesostasis albeit richer in CaO and SiO_2 to allow extensive crystallization of cpx) was acquired during the melting of the ferromagnesian mantle but did not predate the accretion of the two precursors. In addition, layers 1 and 2 shows multiple evidence of an enrichment in SiO_2 of the partial melt of the AOA. Our currently preferred interpretation is thus that the melting of the compound precursor occurred after accretion of the two parts in the conditions of chondrule formation. If the CAI precursor can be ascribed to an AOA, however the ferromagnesian precursor is difficult to identify precisely. The presence of only relicts of olivine and metal suggests that the precursor consisted only of olivine and metal. However evidence of pre-existing glass or pyroxene may have been erased during the last melting event. The differences between the final chondrule-like mantle and type I chondrules are probably due to the larger amount of Al_2O_3 and CaO in the melt coming from the AOA.

More petrological information will be presented at the meeting. O and Mg isotopic measurements are planned to ascertain the present hypothesis and obtain new informations on the geochemical reservoirs in the early solar nebula.

Conclusions: These preliminary results support models of chondrule formation by partial melting and interaction with the nebular gas of pre-existing association of olivine and metal [4]. However our observations are unsufficient to determine the origin of the olivine + metal precursor since no triple junction was conclusively observed due to the pronounced degree of olivine dissolution. Among possible precursors lithic clasts from planetesimals have been proposed [4] but loose aggregates of nebular condensates may also be a possible coating for E-MNHN-002. Finally, we note that such objects may be precursors of Al-rich chondrules [5]. In that respect, E-MNHN-002 may belong to a class of objects that include peculiar Al-rich chondrules consisting of a Ca-Al-rich core and a ferromagnesian mantle, previously found in Acfer 094 [6].

References:

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