MODAL ABUNDANCE, CHEMISTRY AND DENSITY OF CHONDRITES FINE GRAINED MATERIALS BY ADVANCED ELECTRON MICROSCOPY

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Introdution : Primitive chondrites consist of variable proportions of high-temperature constituents (refractory inclusions, chondrules and metal) embedded in a fine-grained matrix [1]. In CM chondrites the constituting matrix is about 70-80 vol. % and represent a major reservoir of primary phases. However, its extremely fine-grained size and its heterogeneous compositions and densities make it difficult to analyze by conventional techniques. Higher resolution techniques are therefore required for mineralogical analysis. To better constrain the nature of these complex matrix materials and the effect of secondary processes (hydrothermal alteration, metamorphism, shock) we developed a new methodology coupling phase cartography (based on low-voltage SEM-EDS) and quantification by electron probe micro-analysis (EPMA). The aim is to simultaneously quantify: a) the composition and modal abundance of submicrometric phases, b) determine the physical properties of grains (grain size, circularity of grains) and density. We apply this methodology to the matrices of the Murchison, Orgueil and Paris chondrites. The Paris chondrite was also chosen because it contains lithologies showing different alteration degrees [2].

Methods: We acquired hyperspectral EDS maps using a field emission scanning electron microscope (FESEM) operated at low accelerating voltage (5-6 kV) which makes it possible to reach a spatial resolution of ≈ 300 nm.

We modeled the EDS Brehmsstrahlung background which is a function of the material density. We used a physical model which takes into account the Kramer emission law, the absorption within the sample, the detector efficiency, and the absorption by the coating layer. Compositions are known from EMPA, which allows us to calculate the mass absoption coefficient so that the mass depth "ρz" is the single free parameter which has to be fitted to the hyperspectral EDS data. This Bremsstrahlung model was integrated into the Hyperspy library [3]. Gaussian functions are then fitted for each X-ray line and the obtained elementary maps are analyzed by a clustering algorithm, and yield a phase cartography with a 250 nm pixel size. For pixels still showing contribution of different phases, a linear combination fit is performed to retrieve the mixing ratio of the different phases. Ultimately, using EPMA data obtained on each phase together with the modal abundances and the densities allows us to calculate the matrix bulk composition by mass balance.

Results : Applied to different meteorites, this methodology makes it possible to describe the mineralogy of fine-grained matrices. Matrices are dominated by a mixture of amorphous silicates and phyllosilicates which represents in volume 76±6 % in Paris, 81±3% in Murchison and up to 94±1% in Orgueil. Anhydrous silicates (olivines and pyroxenes) represent 3±0,5% of the matrix of Murchison and reach 17±2% for the less altered part of the matrix of Paris (0% in Orgueil). In Paris, the amount of amorphous silicates/phyllosilicate is similar in the less and more altered parts of the matrix (75±6% and 79±6%, respectively). Anhydrous silicates seem to decrease slightly from 17±2% to 13±1,4% with increasing alteration. Anhydrous silicates in the Paris meteorite can be separated in two groups: i) rounded fine grains with a circularity above 40 % and a grain sizes below 4 µm (centered around 740 nm) and ii) angular coarse grains with a circularity below 40% and a grains size above 4µm (centered around 10 µm) which can be interpreted as being chondrules fragments. The density determination method applied to one cartography of the Paris matrix reveals variation from 3 to 3.5 ± 0.7 g/cm^3 for the regions containing amorphous/phyllosilicate mixed with nanosulfides.

Lastly, bulk compositions calculated with this new approach are close to chondritic values with some minor deviations. In the case of Orgueil, results are consistent with previous wet chemistry data [4]. Chemical concentrations obtained with this two different methods correlate well (R2 ~ 0.923).

Conclusion: Our new methodology appears to be perfectly suited for the analysis of fine-grained material and shows robustness for different matrices of various alteration degrees. It also made it possible to retrieve chondritic compositions for the fine-grained material of Murchison, Paris and Orgueil. Chemical and mineralogical data obtained with this approach were used to study the differences between fine grained rims and the adjacent matrix in the Paris meteorite. Our results will be presented at this conference [5].

References: [1] A. J. Brearley et R. H. Jones (1998) in *Planetary Materials* **36**, *Reviews in Mineralogy*, 3-1 - 3-398. 2751. [2] Hewins, R. H. et al., (2014) , 124, 190-222. [3] De La Peña, F. et al. (2017) Hyperspy v1.2. [4] Lodders, K. (2009) *Astrophys. J.* 591 (2) , 200. [5] Zanetta P-M., et al. (2018) *this meeting*.