Volatile-rich chondrules and metal-sulfide nodules in enstatite chondrite

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Enstatite chondrites (ECs) constitute the reduced end-member of the undifferentiated meteorites. Like the other chondrites, ECs correspond to complex aggregates of high-temperature components—calcium and aluminum-rich inclusions and chondrules—embedded in a thermally unprocessed matrix. Enstatite chondrites also contain singular and complex metal-sulfide nodules (MSNs) that can represent up to 30-40 vol.% of the meteorites [1] and that do not really have counterparts in other chondrite classes. MSNs are composed principally of Fe-Ni metal and troilite that are often associated with a variety of other sulfides (CaS, (Mg,Mn,Fe)S, etc.), schreibersite ($[Fe,Ni]_3P$), perryite ($[Fe,Ni]_8[Si,P]_3$), graphite and silicates in variable proportions. Although several processes have been proposed (e.g. [2]), the way MSNs formed and/or were reprocessed before accretion remains poorly understood. Petrological observations argue for a continuum between silicate-bearing MSNs and sulfide-bearing chondrules [1]. Sulfides (FeS, CaS and/or (Mg,Mn,Fe)S) are indeed systematically present in EC chondrules. Textures and chemical compositions indicate that most sulfides in EC chondrules are magmatic minerals formed *via* sulfur dissolution and saturation from the molten chondrule [3]. Chondrule mesostases in ECs are also enriched in alkali and volatile elements compared to their counterparts in other chondrites, indicating that they were melted within a volatile-rich gaseous environment [3].

We have performed petrological observations and chemical analyses of silicates and sulfides in both chondrules and MSNs of the unequilibrated EH3 Sahara 97096 (MNHN collection). MSNs generally contain silicates (low-Ca pyroxenes, silica, albitic plagioclase or glass and a porous amorphous silica) as inclusions in kamacite or as intergrowths with sulfide and metal. We selected MSNs containing large silicate-rich assemblages for textural and chemical investigations. The silicate assemblages in MSNs consist mostly of low-Ca pyroxene and silica occasionally associated with mesostasis-like patches. In three MSNs, mesostasis-like patches several 10s of micrometers across show dendritic textures and micrometric low-Ca pyroxene crystals on the borders. Their chemical compositions measured by electron microprobe are comparable to chondrule mesostases, with abundant S, Cl, Na_2O, and K_2O. Isotope micro images of volatile elements using a SIMS IMS-1280 equipped with SCAPS at Hokkaido University were obtained on chondrules and MSNs. The occurrence of volatile elements in the MSN glass indicates that MSNs were melted under high partial pressures of volatile elements, similarly to chondrules, before their accretion on the EC parent body. This reinforces the hypothesis of a genetic link between chondrules and metal-sulfide nodules.

References: [1] Lehner et al. (2014) MAPS 49, 2219-2240 [2] Jacquet et al. Chapter in *Chondrules and the protoplanetary disc*. Cambridge University press. [3] Piani et al. (2016) GCA 195, 84-

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