

SULFUR ISOTOPE COMPOSITION OF SULFIDES IN CARBONACEOUS CHONDRITES AND VOLATILE-RICH, CI- AND CM-LIKE CLASTS FROM VARIOUS CHONDRITES AND ACHONDRITES

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Introduction: Volatile-rich, CI- and CM-like clasts found as lithologies inside many different brecciated meteorite groups, have the potential to represent so far unknown material. The mineralogy of these clasts has often been discussed in literature (e.g., [1,2]). A recent study from [3] extensively discussed a large number of volatile-rich clasts and subdivides these into two main groups; (i) CI-like type (having high abundances of phyllosilicates, magnetite, and sulfides) (ii) CM-like type (having phyllosilicates, tochilinite/cronstedtite intergrowth (TCI), and common chondrules and anhydrous fragments). Both, the mineralogy and the low temperature thermal history resolved by Raman carbon thermometry suggests similar formation histories for both clast types and CI and CM chondrites [4]. Based on these data, a genetic relationship between CI- and CM-like clasts and CI and CM chondrites, respectively, may be established. Sulfur isotope compositions of sulfides, however, tell a completely different story.

Methods: The sulfur isotope compositions were obtained *in situ* using a Cameca 1280 ion probe at the NORDSIM laboratory in Stockholm, Sweden. The mass-dependent fractionation line (MDF) was defined by two pyrite standards (Ruttan and Balmat) and a pentlandite (Norilsk) and pyrrhotite (MV1) standard were used to correct for the type of mineral. Pyrrhotite and pentlandite grains in 49 different clasts from 14 samples have been analyzed for their sulfur isotope composition ($\delta^{33}\text{S}$ and $\delta^{34}\text{S}$). Additional isotopic data were also acquired for sulfides from 8 carbonaceous chondrites (CI, CM, and C2_{ung}) to be able to correlate the isotope compositions of the sulfides from volatile-rich, CI- and CM-like clasts with those from sulfides within known carbonaceous chondrites.

Results and Discussion: All data plot within 2σ error of the MDF. Based on the isotope compositions of sulfides CI, CM, and C2_{ung} carbonaceous chondrites can be easily distinguished. The sulfides in the two CI chondrites mainly have a positive sulfur composition ($\delta^{34}\text{S}$ $1.12\% \pm 0.23$, $n = 37$), whereas the sulfide compositions from CM and C2_{ung} chondrites are primarily negative ($\delta^{34}\text{S}$ $-1.45\% \pm 0.34$, $n = 30$ and $\delta^{34}\text{S}$ $-3.04\% \pm 0.40$, $n = 31$, respectively). The differences between the CM and CI chondrites have previously been assigned to the differences in the degree of aqueous alteration experienced by these chondrites [5]. In the more altered samples (i.e. CI) the scavenging of lighter isotopes during the formation of sulfates results in the later formation of sulfides with a heavier isotopic composition [5,6]. Unlike the CM and CI chondrites, the CM- and CI-like clasts cannot be distinguished from each other ($\delta^{34}\text{S}$ -6.9% to 4.9% $n = 59$ and $\delta^{34}\text{S}$ -8.5% to 4.2% , respectively; $n = 89$) even though the similar mineral compositions and mineral abundances of the groups and the clasts (CM to CM-like; CI to CI-like) would suggest that they experienced similar alteration processes. Another evident feature is the fractionation difference between the sulfide minerals that have been analysed. Pentlandite grains show a significantly lighter isotopic composition compared to the pyrrhotite grains. [3] suggest that during aqueous alteration pyrrhotite is preferably oxidized compared to pentlandite. However, we think that the timing of formation and the origin of the sulfides needs to be clarified in order to explain this dissimilarity in sulfur isotopic composition. The sulfides in CI-like clasts show significantly ($\delta^{34}\text{S}$ $-1.09\% \pm 0.30$, $n = 89$) lighter isotopic compositions compared to those within the CI chondrites ($\delta^{34}\text{S}$ $1.12\% \pm 0.23$, $n = 37$) even though they are mineralogically very similar (e.g., [1-3]) and have experienced similar peak temperatures [4]. Similar results can also be seen for the D/H ratios [7]. This difference can be explained by a different origin and, thus, a different isotopic composition of the formation reservoir. Yet, the effects of the aqueous alteration event on the sulfur budget needs to be carefully assessed to understand the fractionation.

Conclusion: The sulfides in the CM chondrites have a very similar isotopic composition compared with those in the CM clasts, whereas sulfides in CI-like clasts differ in isotopic composition from the sulfides in CI chondrites. The difference can be explained by the timing of formation and the origin of the sulfides; however, more evaluation of the data is needed to determine the exact reason.

References: [1] Wilkening L. L. (1973) *Geochimica et Cosmochimica Acta* 37:1985-1989. [2] Zolensky M. E. et al. (1996) *Meteoritics and Planetary Science* 31: 518-537. [3] Patzek M. et al. (2018) *Meteoritics and Planetary Science* (in review). [4] Visser R. et al. (2018) *Geochimica et Cosmochimica Acta* (in revision). [5] Bullock E. S. et al. (2010) *Meteoritics and Planetary Science* 45:885-898. [6] Sakai H. (1957) *Geochimica et Cosmochimica Acta* 12:150-169. [7] Patzek M. et al. (2017) *Meteoritics & Planetary Science* 52:A267.