Goldschmidt 2021 Abstract
https://doi.org/10.7185/gold2021.8002

Coordinated analysis of the functional group chemistry, elemental and isotopic composition of extraterrestrial insoluble organic matter at the nanoscale

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Insoluble organic matter (IOM) from comets and asteroids consists of complex macromolecule polymers, which vary in microstructure, functional group chemistry, and elemental and isotopic composition. The functional group chemistry group of IOM extracted from meteorites has been studied extensively with synchrotron x-ray absorption near edge spectroscopy (XANES). These studies reveal systematic differences at the bulk scale in aromatic, ketone and carboxyl group abundances that correlate with the alteration histories of the parent asteroids. However, the IOM also often shows heterogeneity at the sub-micron to nanoscale in chemistry, elemental and isotopic composition that reflects distinct pre-accretionary origins with an overprinting of parent body processing effects [1]. The use of low voltage, cold-FEG UHV scanning transmission electron microscopy (STEM) with electron energy loss spectroscopy (EELS) and energy dispersive x-ray spectroscopy (EDS) enables simultaneous measurement of the functional chemistry and elemental compositions at scales down to 1 nm. Compared to XANES alone, the STEM-EELS-EDS measurements help resolve ambiguity in the assignments of features in the C-K edge spectra, e.g., nitriles and ketone, or sulfur-bearing groups, and more readily allow quantitative determination of C:N:O:S abundances. We have used C XANES to characterize IOM from meteorites with a range of different petrographic grades, and subsequently perform STEM-EELS-EDS on the same samples. Our STEM-XANES analyses show that the low voltage STEM methods provide qualitative agreement with XANES results, but that some loss of aliphatic groups that contain H occurs, even for heated meteorites such as ALH 77307 (CO3). NanoSIMS measurements on these samples are planned to assess the beam damage effects on isotopic composition, and to look for correlations of the isotopic composition with functional chemistry and elemental composition. For future Ryugu and Bennu sample analysis, continued reliance on a combination of XANES and STEM-EDX-EELS is the best approach, along with complementary SIMS and optical spectroscopies.

[1] Alexander et al. (2007) Chemie der Erde 77, 227-256.