

Nanoscale study organic matter in Orgueil and Ryugu by STEM-EELS : mitigating beam damage with direct electron detectors

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The organic matter (OM) in chondrites shows evidence of evolution during aqueous alteration in asteroids. It occurs in situ as submicrometric particles, but is otherwise mainly intercalated at the nanoscale between phyllosilicates. Studying its molecular variability requires high spatial resolution accessible only with electron energy loss spectroscopy (EELS) in a TEM. However, OM is sensitive to beam damage. To date, most carbon K edge analyses have been performed using synchrotron-based scanning transmission X-ray microscopy (STXM). X-rays are gentler, but spatial resolution is limited (~ 25 nm).

We take advantage of state-of-the-art direct electron detectors based on medipix technology within a monochromated STEM and optimized the conditions - voltage, pixel size, temperature - to achieve the highest spatial resolution while minimising damage. Measurements are performed simultaneously at low energy (2 - 15 eV) and at the C-K edge using a custom multi-energy, multi-frame acquisition protocol. We studied two different reference polymers (PEEK, PES) as well as the insoluble OM from Orgueil and a FIB section from Ryugu.

We observe mass loss and amorphization through radiolysis / recombination mechanisms and evidence: i) higher sensitivity to damage of aliphatic groups (PES damages faster than PEEK), ii) lower damage at acceleration voltage of 200 keV compared to 80 keV; iii) slower damage at -100°C, but appearance of new functional group through recombination. Most importantly, we observe that for a pixel size lower than 7 nm, even the PEEK damages fast, thus limiting the spatial resolution. This is likely due to damage delocalization that affects material outside the probe itself.

The frame-by-frame analysis of the Orgueil IOM and the

Ryugu FIB section reveals increasing damage (200 keV, 20 nm-sized pixels). Retaining only the undamaged frames, we succeeded in identifying the molecular signature of the more aromatic particles, from that of the more aliphatic diffuse OM intercalated in the phyllosilicates. The obtained spectra are identical to STXM data. We will eventually discuss the molecular diversity of OM in Ryugu and the perspective to reach even higher spatial resolution.