Formation of geopolymers during early diagenesis: the example of the Montceau-les-Mines Lagerstätte

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When living organisms die, organic molecules are in most cases rapidly biodegraded. Yet, a few pathways may allow the macromolecules resistant to biodegradation and some more labile organic molecules to escape the biological cycle and get incorporated into the sediment: (1) selective preservation, (2) degradation/recondensation/sulfurization, (3) adsorption on inorganic surfaces or encapsulation within mineral microcavities or larger molecules. The respective contribution of each of these processes remains debated, but the result is that precisely assessing the origin of organic molecules in sedimentary rocks may sometimes be delicate.

The combination of synchrotron-based scanning transmission X-ray microscopy (STXM) and X-ray absorption near edge structure (XANES) spectroscopy with transmission electron microscopy now offers valuable capabilities for the *in situ* characterization of heterogeneous and organic-rich samples such as fossilized remains [1]. While STXM and XANES allows characterizing organic constituent speciation at the 15 nanometer scale, TEM provides information on organic/inorganic relationships at the sub-nanometer scale.

Here we report the multiscale characterization of exceptionnally preserved soft-bodied organisms fossilized within carbonate concretions from the Carboniferous Montceau-les-Mines Lagerstätte [2]. SEM and TEM investigations have revealed mineralogical heterogeneities at all scale of observations, likely explaining the exceptional morphological preservation of the investigated fossils. STXM experiments (performed using the 5.3.2.2. ALS STXM Polymer beamline [3]) have allowed evidencing the similar molecular signatures of the organics composing the vegetal and the animal remains. This surprising homogeneity is interpreted as resulting from the replacement of the initial biogenic organic molecules by newly condensed recalcitrant geopolymer compounds during early diagenesis.

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