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May traces of life be preserved in metamorphic rocks? A nanoscale structural study of high grade metamorphic vegetal fossils.

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Metamorphic processes are commonly assumed to transform biological organic matter (OM) towards graphite, leading to the complete loss of its original chemistry and structure and thus preventing the preservation of biogenicity. Non-ambiguous biogenic fossils have therefore long been considered as only preserved in sedimentary rocks. This makes a major limitation to the search for life in the geological record, especially with regards to the primitive Earth. However, recent improvements of in situ analytical techniques make possible the combined structural and chemical characterization of metamorphic OM down to the nanometer-scale. In a recent study, we observed that morphological, textural and chemical bio-signatures can be preserved even under high grade metamorphic conditions[1]. Here we present observations of metasedimentary rocks exhibiting fossilized fern spores and vascular tissues. Morphology of these vegetal debris is perfectly preserved although they have been submitted to high-pressure metamorphism ($\sim$360°C, $\sim$14 kbars) during subduction. These metamorphic fossils were found in argillaceous Triassic limestones from the La Vanoise massif (Western Alps, France). We have extracted ultrathin sections from the spore walls and vascular tissues by Focused Ion Beam milling. OM and associated mineralogy were structurally and chemically characterized down to the nanoscale using Transmission Electron Microscopy and Scanning Transmission X-ray Microscopy. In particular, the chemical nature of the carbon functional groups composing these OM and their spatial distribution were documented at a submicrometer scale using high

spatial (∼25 nm) and energy (∼0.1 eV) resolution Near Edge X-ray Absorption Fine Structure (NEXAFS) spectroscopy. Fossilized spores and vascular tissues originate from chemically different precursors. Nevertheless, these metamorphic vegetal debris systematically present textural, chemical and mineralogical heterogeneities which are interpreted as remnants of original biogeochemical heterogeneities. High-grade metamorphism might thus not totally erase structural and chemical bio-features, at least at the submicrometer scale. Such a multiscale characterization approach sheds new light on the fossilization processes of biogenic OM during metamorphism, and more generally on the fate of bio-signatures during geological processes.

[1.] Bernard S., Benzerara K., Beyssac O., Menguy N., Guyot F., Brown Jr G.E. & Goffe B., Preservation of plant fossils in high-pressure metamorphic rocks. *EPSL*, 262, 257-272, 2007