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Characterizing the role of Sulfur in Fossilization: Exploring fossil and organic biomass preservation pathways via detailed spatially resolved organosulfur and inorganic sulfur speciation

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Sulfurization of organic matter is a critical process governing organic preservation (i.e. fossilization) in aquatic systems, an important part of oil and coal preservation, and a key part of how we consider organic matter cycling in a changing modern world. In rare cases, fossil deposits can capture a much more complete record of an ecosystem by preserving soft-bodied organisms. Understanding the connections between fossil preservation and sulfur are crucial for reasons beyond being able to interpret the record of life on Earth. As organic particles sink through the marine water column, some reach the bottom of the seafloor and are buried, but some are remineralized into oxidized carbon compounds, eventually leading to an increase in atmospheric carbon dioxide, which leads to increases in global temperatures. However, sulfurization is known to enhance preservation of particles on the ocean floor, so increasing the sulfurization of organic carbon particles in the ocean could help fight climate change. Our recent study (Olcott et al., 2022; https://doi.org/10.1038/s43247-022-00424-7) of 22 ma spider fossils from the Aix-en-Provence Formation (Aix Fm) suggests for the first time that sulfurization could be an important part of soft-bodied fossil preservation through carbon - sulfur reactions involving spider biomass and the surrounding diatoms providing a microenvironment for sulfate reduction in the surrounding waters. S-K-edge and multi-energy μ-X-ray Fluorescence (μ-XRF) imaging and X-ray Absorption Near Edge Structure (XANES) spectroscopy collected at SSRL Beamline 14-3 revealed sulfur in different oxidation states and organic complexation across two fossilized spider samples representing different proposed preservation mechanisms. Organic sulfur compounds are likely sourced from both biotic mechanisms associated with cellular growth, and abiotic reactions of organic carbon molecules with sulfide and polysulfide. These data are exciting as they show several possible modes of preservation including localized sulfurization associated with diatom mats, broad sulfurization that also maintain soft body tissue, and, for the first time observed, spatial preservation of specific organic sulfur compounds preserving internal soft tissue structures such as lungs not visible using any other technique.