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Diagenetic Overprinting on Organo-Mineral Associations: Implications for Stable and Geologic Preservation of Carbon in Sediments

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The association of organic carbon (OC) with reactive mineral phases (iron hydroxides and clays) represents a major pathway of carbon burial in aquatic sediments. Yet, the resilience of organo-mineral associations under shifting environments and diagenetic redox regimes remains a key unsolved problem, controlling the permanence of carbon deposition and its geological preservation. Therefore, we investigated the stability of OC-minerals across surface to subsurface intervals of a terrestrial to marine transect, quantifying and characterizing both iron and clay associated OC. Sequential extraction of minerally associated fractions combined with multi-proxy analyses of mineralogical (composition, surface loading), dual isotopic (stable and radiocarbon), elemental (C, Fe, N), and molecular (n-alkane biomarkers) profiles enabled us to track compositional changes in different organo-mineral complexes across these spatiotemporal gradients.

We observe different binding affinities and efficiencies in iron (hydr)oxides and clay minerals, with distinct responses to diagenetic and depositional controls. In subsurface anoxic layers of slowly accumulating marine sediments, prolonged exposures to reducing conditions and anaerobic microbial metabolism promote the dissolution of iron phases after burial, leading to mobilization of up to ~50% of its initially associated OC. In contrast, stations close to land that are affected by enhanced terrigenous inputs and higher sedimentation rates, exhibit up to a ~60% increase in clay-associated OC in deep layers compared to recently deposited layers. Such a cumulative behaviour through time indicates that phyllosilicates display progressive sorptive retention and/or selective preservation toward OC. Hence, our findings demonstrate that preserved pools are dynamic and compositionally evolving, rather than permanently stable. Depending on the mineral backbone and surrounding regime, organo-mineral associations can be restructured and overprinted, archiving modified quantities and composition of carbon in sediments. Therefore, accounting for depositional and post depositional alteration is essential to refine paleo environmental reconstructions, budget estimates, and our understanding of geological cycling of carbon.