

Mechanisms of Mineral-Mediated Soil Organic Carbon Stabilization: Enzyme Inhibition versus Substrate Protection

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Enzymatic degradation of soil organic carbon (SOC) represents a critical process in the context of soil organic carbon storage. Secondary minerals (e.g., iron oxides and clay minerals), known for their high specific surface area and strong binding capacity, protect SOC from enzymatic degradation through two possible mechanisms: (1) inhibition of extracellular enzyme activity via surface adsorption, potentially blocking enzyme active sites or altering their conformation, and (2) stabilization of SOC through mineral-organic complexation. However, the synergistic interplay between these mechanisms has made it challenging to disentangle their individual contributions, potentially leading to an oversight of their distinct roles.

The study presented here addresses this knowledge gap. By employing size exclusion chromatography (SEC) to analyze the size distribution of biomacromolecules and their degradation products, we demonstrate that while mineral-induced suppression of enzyme activity is consistently observed, direct mineral-mediated stabilization of SOC also plays a non-negligible role. Specifically, mineral adsorption of enzymes typically reduces their activity, thus slowing SOC degradation. However, the adsorption of SOC by minerals can prevent its degradation even in the presence of active enzymes, effectively enabling the sequestration of SOC. The degree of protection and the dominant mechanisms are influenced by multiple factors, including the elemental composition and surface properties of minerals, the structural conformation and size of biomacromolecules, and the form and strength of mineral-biomacromolecule associations. These findings decouple the roles of "mineral-enzyme" and "mineral-organic" interactions in SOC preservation, offering new insights into mineral-mediated SOC sequestration and its implications for mitigating CO₂ emissions.