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The mineralogical capacity of soils to store carbon: sequestration and vulnerability in a changing climate

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Soil – the largest terrestrial pool of actively-cycling carbon – has the potential to sequester vast amounts of carbon globally. Chemical- and physical-associations of organic matter with mineral surfaces are known to play a critical role in this storage and preservation. However, the maximum capacity of soils to store carbon globally, and the role of mineralogy in driving this limit and its spatial variation, is still unknown. Here we present a comprehensive analysis of mineral-associated carbon and auxiliary variables from sites that span diverse biomes and soil types. We find that soil mineralogical properties dictate the maximum capacity of soils to stabilize organic matter associated with minerals, and that this mineral-associated organic matter accounts for the majority of carbon and nitrogen in soil organic matter. Explicit representations of mineral-organic associations are still lacking in Earth system models, and our findings are essential for informing and parameterizing model formulations at global scales. Our results suggest that most soils contain substantially less carbon than their mineral-associated carbon capacity (i.e. they are below carbon saturation), and that this is particularly evident in deeper soils and in poorly-managed and degraded lands. We calculate the mineralogical limit of low- and high-activity mineral soils to stabilize carbon, and use these empirically-derived limits to estimate the global potential for soil minerals to stabilize carbon. This estimate, and the underlying spatial distribution, provides crucial insights and motivation for targeted soil management and conservation efforts. Increasing soil carbon storage through restoration is a promising avenue for mitigating global emissions with lasting co-benefits.