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Lithium isotopes in soil unlock the coupling of silicate weathering and organic carbon cycling

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Chemical weathering of silicate minerals and burial of organic carbon (OC) in soil regulate atmospheric CO_2, but their impact on one another is contested. For example, OC oxidation in soil can generate acids that drive silicate weathering reactions. Yet, silicate weathering produces clay minerals that can occlude OC and limit oxidation. Whether silicate weathering and OC cycling compete or cooperate in soil remains debated, in part because we lack quantitative tools that can simultaneously probe these processes. To address this problem, we propose that Li isotope ratios in river suspended sediment or soil, which are commonly used to track clay mineral formation, can also be used as a proxy for soil OC content.

We first test this idea by measuring Li isotope ratios and OC content of river suspended sediment from two watersheds (Little Deschutes River, Oregon, USA and Rio Bermejo, Argentina) with contrasting physiographic attributes, and compare these measurements with published soil OC and Li isotope records across a chronosequence from Hawaii. All sites show a strong negative correlation between sediment $^7Li/^6Li$ ratios and OC content, showcasing that increased clay formation is associated with increased OC content. However, the sites differ in their ranges of $^7Li/^6Li$ ratios and OC contents, which is likely due to bedrock chemistry (i.e., intrinsic weathering rates) and analyzed material (i.e., suspended river sediment vs. bulk soil). To explain these observations, we designed a simple box model for soil formation that couples OC transfer with fluid flow, silicate weathering, and Li isotope transfer. We determine that Li isotope and OC trends are most sensitive to rates of mineral dissolution and precipitation, where higher weathering rates typically beget greater OC stocks and lower $^7Li/^6Li$ ratios. Moreover, how we couple OC cycling and silicate weathering (e.g., through ligand promoted dissolution and/or clay occlusion) does not appear to affect the pathway of soil formation but rather the time progress along the pathway. Together, these findings suggest that with estimates of weathering rates and durations, Li isotopes can help elucidate the coupling of OC cycling and silicate weathering, and their responses to past and present climate change.