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Li and U series isotopes constrain the control of bedrock on landscape denudation

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The conversion of bedrock to solutes during chemical weathering underlie nutrient cycles at the Earth's surface. Isotope ratios of river solutes are increasingly used to characterize the nature of weathering in the Critical Zone, with each proxy only depicting a subset of the total system function. The paired usage of lithium (Li) and uranium (U) isotope ratios is especially tantalizing because they can together convey the degree of secondary mineral formation, comminution of mineral grains, and timescales of water-rock interaction, thus constraining the coevolution of sediment and solute mass at the watershed scale. However, studies that pair these isotope systems restrict their analysis to a given watershed, providing useful insights but ones less broadly applicable across varied Earth surface conditions.

To construct a coherent framework for interpreting river solute δ^7Li values and ($^{234}U/^{238}U$) ratios, we compile published, paired measurements of these isotope ratios and determine watershed-average climate, morphometrics, and lithologic attributes for each sample. The compilation data show a positive monotonic relationship between δ^7Li_{river} values and $(^{234}U/^{238}U)_{river}$ ratios, suggesting that the signature of clay mineral formation is associated with the weathering of fine, alpha recoil-damaged sediment. Yet, when samples are grouped and regressed according to exposed bedrock type, the δ^7Li-($^{234}U/^{238}U$) arrays show varying slopes, with a sedimentary rock array having a steep slope and volcanic and metamorphic arrays having respectively shallower slopes. We develop a self-consistent one-dimensional reactive transport model of Li and U isotope transfer to interpret these arrays and show for the first time the mutual dependence of bedrock composition on these weathering proxies. Model sensitivity analyses reveal that the slope of δ^7Li-($^{234}U/^{238}U$) arrays are most sensitive to mineral grain size and primary mineral dissolution rates, where steep slopes are predicted when both grain size and dissolution rates are low. Together, the compilation and the model predictions emphasize the prevailing importance of rock erodibility on the style of weathering across landscapes, with implications for the role of bedrock composition in Critical Zone architecture and global geochemical cycles.