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Enhanced ^{234}U Mobilization from Bedrock Incipient Weathering: Implications for Marine ^{234}U Budgets

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^{234}U is a pivotal radioactive tracer for unraveling sediment weathering and transport mechanisms, with its isotopic signature preserved in marine fossils and sedimentary archives. Despite its importance for understanding the global uranium cycle—particularly in marine settings—its budget and precise sources remain only partially resolved. Current estimates place the marine ^{234}U excess at approximately 3.74×10^{10} g, a figure exceeding traditional continental flux models, which largely attribute ^{234}U delivery to weathering within the critical zone (CZ). Under the assumption of a globally averaged CZ thickness of 37 m, these models predict a ^{234}U flux of merely 1.96×10^{10} g, thereby leaving a substantial shortfall in the global uranium budget.

In this study, we investigate the preferential leaching of ^{234}U from the uppermost 10 m of bedrock—immediately below the CZ—as a key factor in accounting for this deficit. Drawing on a comprehensive global compilation of published uranium isotope data, we conducted a statistical analysis of ($^{234}U/^{238}U$) ratios in bedrock profiles, focusing on the top 10 m where microfractures and fluid pathways are most abundant. This zone exhibits an average ($^{234}U/^{238}U$) ratio of 0.966 (n = 87), underscoring significant ^{234}U depletion via alpha-recoil–induced leaching. Mass balance calculations indicate that this shallow bedrock interval releases approximately 1.78×10^{10} g of ^{234}U. When added to the CZ-derived flux of 1.96×10^{10} g, the combined supply of 3.74×10^{10} g matches the observed marine excess.

These findings reveal that microfracture-enhanced leaching in shallow bedrock appreciably augments continental ^{234}U fluxes, challenging the prevailing view that saprolite weathering within the CZ alone governs uranium mobilization. By demonstrating the need to incorporate bedrock incipient weathering processes into geochemical frameworks, our work offers a more nuanced and accurate perspective on the global uranium cycle and its influence on marine ^{234}U budgets.