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The chemical weathering engine of upland landscapes

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Upland landscapes are chemical reactors which convert bedrock into the lithogenic components of soil, the rock-derived nutrients of ecosystems and the base cation composition of groundwater and streams. The drivers of this conversion generally include exposure of bedrock to actively draining meteoric water, oxygenation under partially saturated conditions, ingrowth of roots and attendant rhizodeposition and carbon respiration. How these dynamic environmental drivers combine and interact to produce soils, nutrients and stream chemistry is still widely debated. Now, a new generation of instrumentation is yielding the data necessary to develop process-based models, offering a series of new insights into the chemical reactor below shallow mobile soils. Here, we show that in climates subject to strong seasonal wet and dry periods, water content varies meters below the land surface as a result of the water demand of deeply rooted ecosystems. This wetting and drying of the weathering profile is accompanied by seasonal oscillations in oxygen content (pO_2), decreasing as volumetric water content increases and diffusion is impeded, and rebounding when water contents decrease. In contrast, attendant carbon dioxide concentrations (pCO_2) remain elevated and relatively stable across seasons, leading to comparably stable base cation concentrations produced through carbonic acid – driven weathering. We show that this elevated pCO_2 at depth is a product of root respiration occurring meters below soil, where the diffusive length scale to the atmospheric boundary condition is elongated and higher pCO_2 values can build up. The seasonal stability of this pCO_2 is, however, associated with the higher solubility of inorganic carbon in water relative to O_2, leading to greater buffering against seasonal water content oscillations and ultimately a departure from typical pO_2:pCO_2 respiratory quotients observed in shallower soils. In combination, these unique features of the deep weathering profile attenuate strongly dynamic environmental drivers, yielding relatively stable base cation concentrations which may ultimately set the foundation for widely observed chemostatic concentration-discharge relationships in the streams draining these upland systems.