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Quantifying nutrient uptake as driver of rock weathering in forest ecosystems by magnesium stable isotopes

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Plants and soil microbiota play an active role in rock weathering and potentially couple weathering at depth with erosion at the soil surface. The nature of this coupling is still unresolved because we lacked means to quantify the passage of chemical elements from rock through higher plants. In a temperate forested landscape of the Southern Sierra Critical Zone Observatory (SSCZO), California, we measured magnesium (Mg) stable isotopes that are sensitive indicators of Mg utilisation by biota. We find that Mg is highly bio-utilised: 50-100 % of the Mg released by chemical weathering is taken up by forest trees. To estimate the tree uptake of other bio-utilised elements (K, Ca, P and Si) we compared the dissolved fluxes of these elements and Mg in rivers with their solubilisation fluxes from rock (rock dissolution flux minus secondary mineral formation flux). We find a deficit in the dissolved fluxes throughout, that we attribute to the nutrient uptake by forest trees. Therefore, both the Mg isotopes and the flux comparison suggests that a substantial part of the major element weathering flux is consumed by the tree biomass. This isotopic and elemental compartment separation is preserved only if the mineral nutrients contained in biomass are prevented from re-dissolution after litter fall, showing that these nutrients have been removed as "solid" biomass. The enrichment of ^{26}Mg over ^{24}Mg in tree trunks relative to leaf litter suggests that this removal occurs mainly in coarse woody debris (CWD). Today, CWD is exported from the ecosystem by tree logging. Over pre-anthropogenic weathering time scales, a similar removal flux might have been in operation in the form of natural erosion of CWD. Regardless of the removal mechanism, our data provides the first direct quantification of biogenic uptake following weathering. We find that Mg and other bio-elements are taken up by trees at up to 7 m depth, and surface recycling of all bio-elements but P is minimal. Thus, in the watersheds of the SSCZO in which weathering is fast and kinetically-limited, the coupling between erosion and weathering might be established by bio-elements that are taken up by trees, not recycled and missing in the dissolved river flux due to erosion as CWD and as leaf-derived bio-opal for Si. We suggest that the partitioning of a biogenic weathering flux into eroded plant debris might represent a significant global contribution to element export after weathering in eroding mountain catchments that are characterised by a continuous supply of fresh mineral nutrients.