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Erosion and chemical weathering of siliceous rocks at the supply and kinetic limits

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The uplift and erosion of active mountain ranges and the consequent weathering of minerals modulates the global carbon cycle and impacts Earth's climate on geologic timescales. However, the link between erosion and weathering is complex because weathering rates can be limited by the supply of minerals to the weathering zone, by the supply of acidic fluids, or by the kinetics of mineral weathering. Existing approaches that model the carbon cycle over geologic timescales assume that with increasing erosion rates, weathering transitions from a supply limit where weathering rates scale linearly with erosion to an 'acid' or a kinetic limit where weathering is insensitive to erosion. Alternative models fit a single power-law to the relationship between erosion and weathering across multiple orders of magnitude. The validity of these two approaches remains difficult to assess at the landscape scale because existing data do not cover all limits or because co-variation between runoff and erosion obscures the driver of changes in weathering rates. Here, we compile five datasets of solute concentrations in streams that span well-defined erosion rate gradients in relatively uniform lithologies and with limited or well-constrained variations in runoff. Across 2-3 orders of magnitude of erosion rates, and for both metasedimentary and granitic lithologies, we find that silicate weathering rates are insensitive to erosion rates. In turn, weathering of sulfide and carbonate minerals increase with erosion rates, consistent with a limitation by mineral supply. However, contrary to existing models of supply-limited weathering, we observe a non-linear increase of sulfide and carbonate weathering rates with erosion. These new findings suggests that supply-limited and kinetically limited zones of weathering co-exist within a single landscape across multiple orders of magnitude of erosion rate. The distribution of these zones is most likely controlled by erosion processes. As a consequence, existing weathering models that assume a linear relationship between erosion and weathering at the supply limit may overestimate the sensitivity of weathering rates to erosion and underestimate the impact of climate on these reactions, with implications for the effect of mountain building on the carbon cycle and on Earth's climate.