Supply-limited and kinetic-limited chemical erosion

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Downslope transport of hillslope sediment is often usefully cast in terms of two end-members of a spectrum of erosional regimes. At one end of the spectrum, 'transport-limited' physical erosion develops when downward propagation of weathering outpaces erosional losses from a slope, such that the removal of material is limited only by the sediment transport rate [1]. At the other end of the spectrum, 'weathering-limited' erosion develops when sediment transport matches the rate at which physically competent material loses its structural integrity, such that erosional removal of material is limited by how fast it breaks down by weathering [1]. As originally defined, the concepts of transport-limited and weathering-limited erosion only strictly apply to physical fluxes, yet they are commonly misappropriated in discussions of chemical fluxes. We suggest the interpretive framework for hillslope processes needs to be clarified and expanded for studies of chemical fluxes. Here we define and discuss two end-members in a spectrum of possible chemical erosion regimes. On one end, 'supply-limited' chemical erosion develops when physical erosion rates are slow enough (or regolith residence times are long enough) that further chemical erosion of regolith is not possible due to exhaustive depletion of reactive phases [2, 3]. On the other end, 'kinetic-limited' chemical erosion develops when physical erosion is so fast that chemical erosion can only partially deplete regolith of its weatherable phases before they are removed from slopes [3]. Using published data from field and modeling studies, we show how supply-limited and kinetic-limited chemical erosion can be distinguished from one another based on differences in relationships between chemical erosion rates and mineral supply rates—two variables that can be measured in mountainous landscapes using cosmogenic nuclides.

[1] Carson & Kirkby (1972) *Hillslope Form & Process*.
[2] Riebe *et al*. (2004) *Earth Planet. Sci. Lett*. **224**, 547–562.
[3] West *et al*. (2005) *Earth Planet. Sci. Lett*. **235**, 211–228.

Inferring process from provenance using apatite (U-Th)/He ages of coarse sediment in mountain streams

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The lithology and size distribution of sediment in a streambed reflects a jumble of integrated processes, from the breakdown of bedrock on slopes to selective transport and comminution as particles bash together in transit downstream. If this jumble could somehow be disentangled, it would reveal much about how physical and chemical processes shape landscapes. Here we show how processes of sediment production, transport, and breakdown can be resolved in new quantitiative light using a novel methodological adaptation of existing sediment tracing techniques. If apatite-helium (AHe) cooling ages in bedrock increase with elevation, the distribution of AHe ages in stream sediment reveals the distribution of elevations of sediment source areas [e.g. 1]. To the extent that differences in source elevations reflect differences in geomorphic processes [1, 2], AHe ages in sediment can provide a powerful indicator of the dominant modes of landscape change in a watershed [1, 3]. However, previous AHe tracer studies have focused solely on sand, which represents a small fraction of bed sediment in steep mountain streams where the technique has been applied. Hence, insight on the production and delivery of sediment from hillslopes remains incomplete. Moreover, source elevations of sand reveal little about the movement and downstream fining of coarse sediment in channel networks. Here we show how a much fuller understanding of weathering, erosion, and sediment transport can be obtained by quantifying AHe ages in all grain size classes, including sand, gravel, cobbles, and boulders. What controls the grain size distribution of sediment supplied to channels? Where do boulders come from? How long do they persist in mountain streams? How important is particle comminution in the downstream evolution of grain size distributions? We show that answers to such fundamental questions about surface processes are within closer reach through AHe tracing of coarse sediment.

[1] Stock *et al*. (2006) *Geology* **34**, 725–728. [2] Tranel *et al*. (2011) *Bas. Res*. **23**. [3] McPhillips & Brandon (2010) *Earth Planet. Sci. Lett*. **296**, 373–383.