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Weathering, Erosion, and the Tempo of Landscape Change: A Theoretical Evaluation

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Chemical and mechanical disintegration of rocks near the Earth's surface contributes to denudation in part by reducing intact bedrock to transportable regolith. Here, numerical modeling is used to analyze the interaction between regolith production, transport, and erosion under varying climate. The model computes the evolution of topography and regolith thickness in a small watershed, under the action of four concurrent processes: regolith production, hillslope (diffusive) transport, runoff-driven (advective) transport, and bedrock scour. Two key findings emerge from the analysis. Firstly, the model predicts a two-phase, non-linear sediment-yield curve in response to an increase in climatic erosivity (e.g., larger and/or more frequent storms). This behavior largely reflects the finite supply of regolith on hillslopes; as available regolith is exhausted, sediment supply drops precipitously, and the resulting signal propagates downstream through the channel network as a shift from aggradation to incision. Secondly, repeated oscillations in climate are predicted to drive a highly punctuated denudation-rate response, with weathered material being alternately stored on, and stripped from, hillslopes.

To address the role of short-term variability in precipitation (i.e., variable storm and flood sizes), a stochastic approach is used to estimate long-term average rates of erosion and sediment transport as a function of rainfall magnitude-frequency characteristics. This approach makes it possible to link models of long-term physical erosion with observed climate statistics. One implication is that landscapes with higher runoff-generation thresholds (typically vegetated, humid regions) should show a larger sensitivity to climate fluctuation than those with low hydrologic thresholds (typically arid regions), all else being equal. The stochastic approach can in principle also be applied to predict long-term weathering rates, based on probabilistic models of soil moisture and solute fluxes. To achieve this, however, will require overcoming several important unknowns in the relationship between hydro-climatology, subsurface hydrology, and chemical weathering rates.