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Three grand challenges in geomorphology: rock, climate, and life (Arthur Holmes Medal Lecture)

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To explain and predict the form and evolution of the earth's surface we need: mechanistic understanding of processes; constitutive relationships to solve mass conservation and transformation equations; analytical and numerical models to assemble and test our understanding; quantitative metrics of landscapes; and an understanding of the deep history of the land. New dating methods, high resolution digital elevation data, and a generation of skilled, creative researchers have led to significant advances. The most difficult challenges, nonetheless, lie ahead. A 2010 U.S. National Research Council report, "Landscapes on the Edge", reviews grand challenges in Earth surface processes. Here I focus on three grand challenges in geomorphology: to account quantitatively for how landscape morphodynamics depend on 1) lithology, 2) climate, and 3) life. These are the surprisingly ordinary factors that simple logic says should matter, and, indeed, introductory textbooks typically discuss each of these and offer qualitative inferences that seem reasonable. But take a step towards quantification with a goal of prediction, and we quickly stop. One can look at these challenges through the perspective of how one can solve the conservation of mass equation that forms the basis for predicting surface evolution. For this we need, what can be called *geomorphic transport laws*, which are mathematical statements derived from a physical principle or mechanism, which express the mass flux or erosion caused by one or more processes in a manner that: 1) can be parameterized from field measurements, 2) can be tested in physical models, and 3) can be applied over geomorphically significant spatial and temporal scales. Although work has begun, we have little knowledge yet on how to account in such "laws" for the influences of bedrock, climate, and life. Some example questions which will be discussed: How can we predict, mechanistically, the erosion rate of bedrock landscapes? How do processes and their rates of transport shift with climate? Is there a topographic signature of life?