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Hillslope, river, and Mountain: some surprises in Landscape evolution (Ralph Alger Bagnold Medal Lecture)

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Geomorphology, like the rest of geoscience, has always had two major themes: a quest to understand the earth's history and 'products' - its landscapes and seascapes - and, in parallel, a quest to understand its formative processes. This dualism is manifest in the remarkable career of R. A. Bagnold, who was inspired by landforms such as dunes, and dedicated to understanding the physical processes that shaped them. His legacy inspires us to emulate two principles at the heart of his contributions: the benefits of rooting geomorphic theory in basic physics, and the importance of understanding geomorphic systems in terms of simple equations framed around energy or force. Today, following Bagnold's footsteps, the earth-surface process community is engaged in a quest to build, test, and refine an ever-improving body of theory to describe our planet's surface and its evolution. In this lecture, I review a small sample of some of the fruits of that quest, emphasizing the value of surprises encountered along the way.

The first example involves models of long-term river incision into bedrock. When the community began to grapple with how to represent this process mathematically, several different ideas emerged. Some were based on the assumption that sediment transport is the limiting factor; others assumed that hydraulic stress on rock is the key, while still others treated rivers as first-order 'reactors.' Thanks in part to advances in digital topography and numerical computing, the predictions of these models can be tested using natural-experiment case studies. Examples from the King Range, USA, the Central Apennines, Italy, and the fold-thrust belt of Taiwan, illustrate that independent knowledge of history and/or tectonics makes it possible to quantify how the rivers have responded to external forcing. Some interesting surprises emerge, such as: that the relief-uplift relationship can be highly nonlinear in a steady-state landscape because of grain-entrainment thresholds; that transient landscapes are better than steady state cases for discriminating between models; and that an important part of the job for some rivers is unearthing their valleys after a major event such as an earthquake fills them up. These examples suggest that the 'the simplest possible model' isn't always the one that our intuition expects.

A second example concerns hillslope evolution. Laboratory experiments, field measurements, and the- ory make it clear that, as with rivers, the evolution of hillslopes can involve a strongly nonlinear relationship between relief and erosion rate. Models of particle transport suggest that this nonlinearity can arise from increasingly long-distance particle motions as the gradient increases. One current challenge, therefore, is understanding the dynamics of steep, rocky hillslopes. Among the best natural laboratories for studying such hillslopes are normal-fault facets. These features are a bit like time machines: the higher you go, the longer the surface has been exposed to erosion. A simple mathematical model of facet evolution predicts that the slope of the facet is set by the ratio of erosion rate to fault slip rate. Applying this concept to a case study in Italy where the slip rate is known leads to the startling conclusion that the average hillslope erosion rates over the past $\sim$100 ky is about 20 times faster than the Holocene rate. Thus, facet analysis seems to provide a method for documenting hillslope erosion rates and their variation with climate.

As the quest continues, there are surely more fascinating surprises in store.