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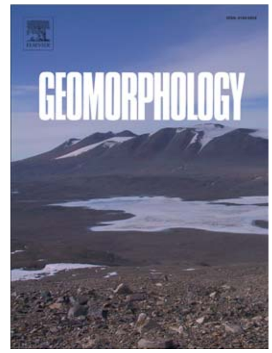

Toward a unifying constitutive relation for sediment transport across environments

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Toward a unifying constitutive relation for sediment transport across environments

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Abstract

Landscape evolution models typically parse the environment into different process domains, each with its own sediment transport law: e.g., soil creep, landslides and debris flows, and river bed-load and suspended-sediment transport. Sediment transport in all environments, however, contains many of the same physical ingredients, albeit in varying proportions: grain entrainment due to a shear force, that is a combination of fluid flow, particle-particle friction and gravity. We present a new take on the perspective originally advanced by Bagnold, that views the long profile of a hillsope-river-shelf system as a continuous gradient of decreasing granular friction dominance and increasing fluid drag dominance on transport capacity. Recent advances in understanding the behavior and regime transitions of dense granular systems suggest that the entire span of granular-to-fluid regimes may be accommodated by a single-phase rheology. This model predicts a material-flow effective friction (or viscosity) that changes with the degree of shear rate and confining pressure. We present experimental results confirming that fluid-driven sediment transport follows this same rheology, for bed and suspended load. Surprisingly, below the apparent threshold of motion we observe that sediment particles creep, in a manner characteristic of glassy systems. We argue that this mechanism is relevant for both hillslopes and rivers. We discuss the possibilities of unifying sediment transport across environments and disciplines, and the potential consequences for modeling landscape evolution.

1 Introduction

Much of the Earth's surface is composed of granular material: soil, mud, sand, pebbles and boulders. Under various combinations of water and gravity, these materials give and flow to evolve landscapes. Decades ago, Bagnold proposed that dry granular flows and fluid suspensions are two limits of a continuum of Earth-material flows, that represent a gradient in sediment:fluid concentration (Bagnold, 1954, 1956). In practice, however, predicting sediment transport rate in even the simplest of circumstances is a daunting task. Consider that dry sand alone may behave as a solid, liquid or gas (Jaeger et al., 1996, MiDi, 2004) — and that the transitions among these regimes are still not well understood — and we begin to appreciate the challenges of incorporating effects such as fluid turbulence, grain size and shape heterogeneity, pore pressure, and cohesion. Moreover, velocity scales of interest for sediment movement in natural landscapes range from 10^{-10} m/s for slow-moving landslides (Di Maio et al., 2013) to 10^{0} m/s for grains suspended in rivers (Bouchez et al., 2011) and turbidity currents (Xu, 2010).

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