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TITLE: Granular Mechanics of Debris-Flow Incision: Measuring and Modeling Grain-Scale Impact Forces

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ABSTRACT BODY: Although steep valleys are ubiquitous in mountainous terrain and there is evidence that episodic scour by debris flows is an important erosional process in these valleys, there is no agreed upon mechanical framework to describe debris flow incision into bedrock. In this work, we take steps towards a defensible stochastic debris flow incision rule. We first characterize frequency-magnitude distributions of basal force using measurements made with a force plate that was overridden during natural debris-flow events that incised bedrock. With these measurements in mind, we use grain-scale numerical experiments (discrete element method simulations) of free-surface, gravity-driven granular flows to quantify how changes in field measureable channel and flow properties (channel slope, flow depth, and grain size) influence the erosive potential of a flow.

The basal force during five monitored natural debris-flow events had a large-magnitude, high-frequency fluctuating component. Variability in force magnitude that resulted from the fluctuating component increased linearly with the time-averaged mean basal force. Probability density functions of basal normal forces greater than the mean force were best fit by generalized Pareto distributions with well-defined means and variances. In contrast, probability density of basal normal force from simulated monodispersed flows decayed much more rapidly and in an exponential manner with increasing force magnitude. Only when monodispersed flows were replaced by broad grain size distributions, characteristic of natural debris flows, did the distributions of simulated impact forces have a similar form to those measured beneath the natural flows. These results highlight the important role flow grain size can have on basal impact force.

As either bed inclination or flow depth was increased in the simulated flows, the mean and the spread of the impact force and impact energy distribution increased as well and in a nonlinear fashion. Bed impact flux was largely decoupled from the downstream flux of particles and was a linearly decreasing function of slope once slope increased beyond a threshold value. Incision rate, which should scale as the product of impact energy and impact flux, increased as a nonlinear function of slope. Steep landscapes in which millennial scale erosion rates have been quantified display a similar nonlinear relationship between erosion rate and channel gradient.

This suggests that the grain-scale mechanics quantified here could place strong controls on steepland morphology that evolves over thousands to millions of years.

KEYWORDS: [1810] HYDROLOGY / Debris flow and landslides, [1815] HYDROLOGY / Erosion, [1848] HYDROLOGY / Monitoring networks, [1847] HYDROLOGY / Modeling.

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