
CREEPY LANDSCAPES: THE ORIGINS AND CONSEQUENCES OF SUB-THRESHOLD TRANSPORT

C. Ortiz^{1,2}, B. Ferdowsi¹, M. Houssais³, D.J. Durian² & D. Jerolmack¹

¹*Dept. Earth and Environmental Science, University of Pennsylvania, Philadelphia, USA*

²*Dept. Physics and Astronomy, University of Pennsylvania, Philadelphia, USA*

³*Levich Institute, City University of New York, USA*

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Determining the threshold of motion is the zeroth-order problem in geomorphology: under what conditions does transport begin? Recent experiments by our group and others, examining fluid-driven granular transport typical of rivers, have revealed glassy dynamics. In particular: (1) as fluid stress is decreased, the dynamics of particle motion become progressively slower and more heterogeneous indicating a continuous (glass) transition from flowing to jammed; and (2) particles exhibit localized but persistent motion at fluid stresses far below the apparent yield condition, which is characteristic of creep in disordered solids [1]. While a generalized version of a local granular rheology model captures well the flow behavior for particles in bed load and suspension, such models predict a transition to a completely jammed state at a finite yield stress — in contradiction to observed creep dynamics [2]. We present new experimental results that demonstrate two important consequences of sub-threshold creep: (1) it contributes to long timescale changes in the rigidity of the pack through the development of a granular fabric; and (2) it drives vertical segregation of grains throughout the pack, which may be an overlooked but dominant factor in river-bed armoring. We perform Discrete Element Model (DEM) simulations that reveal that observed creep dynamics are insensitive to the presence of the fluid, suggesting a direct link between creep on hillslopes and in river beds. Soil creep on hillslopes is most often described using a heuristic nonlinear flux law relating transport rate to slope, and these dynamics have not been linked to the underlying granular motion. Our DEM simulations demonstrate that creep may occur for slopes significantly below the angle of repose, even in the absence of perturbations. They also show that the nonlinear flux law represents a transition from sub-threshold creep to a dense granular flow that is identical to that observed in our river experiments. The emerging view is that sub-threshold creep is the ubiquitous landscape process, and that the onset of both bed-load transport and landslides/debris flows represents a sharp but continuous transition from creeping to dense granular flow.

References

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