Modeling the 2-D evolution of blocky landscapes: Coupled model design

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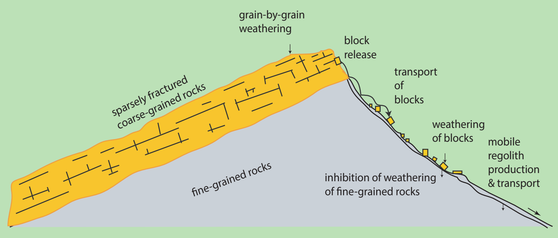
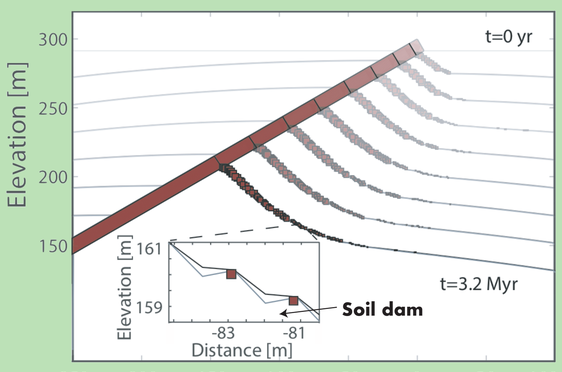
How do blocks of rock influence canyon evolution?

Large blocks of rock are common in steep landscapes developed in a resistant lithology. However, the influence of blocks on landscape evolution is not well known. We developed a hybrid discrete-continuum coupled numerical model of hillslope and channel evolution in the presence of blocks (BlockLab). This is the first model to account for the role of blocks in channel hillslope evolution feedbacks (CHEFs), allowing us to better model the evolution of real landscapes.

Model Components

Hillslope

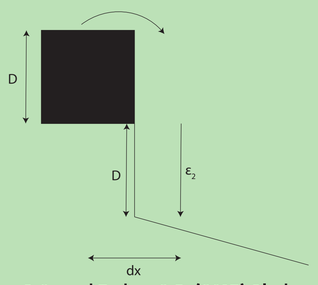




Blocks control hillslope form and erosion rates[1,2]

Continuum rules:
-Depth-dependent soil transport
$q = -kSh^{*}(1-e^{-H/h^{*}})$
-Depth-dependent soil production:
$w = w_0 e^{-H/w^{*}}$

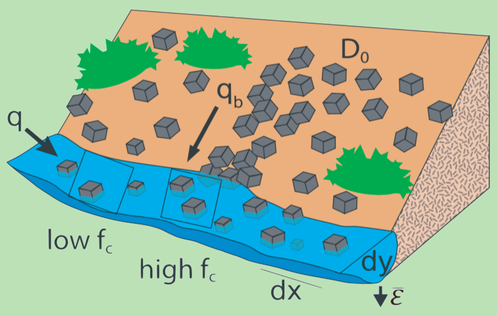
Discrete rules:
-Blocks occupy a full model cell
-Constant block weathering
-Block release relief threshold
-Discrete block movement
$v = \varepsilon dx/D$

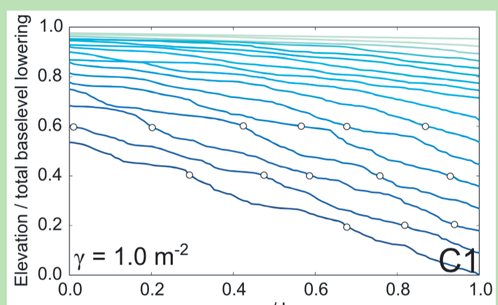


1) Glade, R.C., Anderson, R.S., and Tucker, G.E. (2017) Block-controlled hillslope form and persistence of topography in rocky landscapes: Geology, v. 45, p. 311-314, doi:10.1130/G38665.1.

2) Glade, R.C., and Anderson, R.S. (2018) Quasi-steady evolution of hillslopes in layered landscapes: An analytic approach: JGR Earth Surface, 10.1002/2017JF004466.

Channel





Blocks control channel form and erosion rates[3,4]

Fluvial incision:
-Modified shear stress rule
$\varepsilon = k_b(\tau_b - \tau_c)^a(1-f_c)$

-Basal shear stress with blocks
$\tau_b = \rho g H S/(1+\sigma_D)$

where $\sigma_D = C_D \beta^2 h_b D/2\lambda^2$

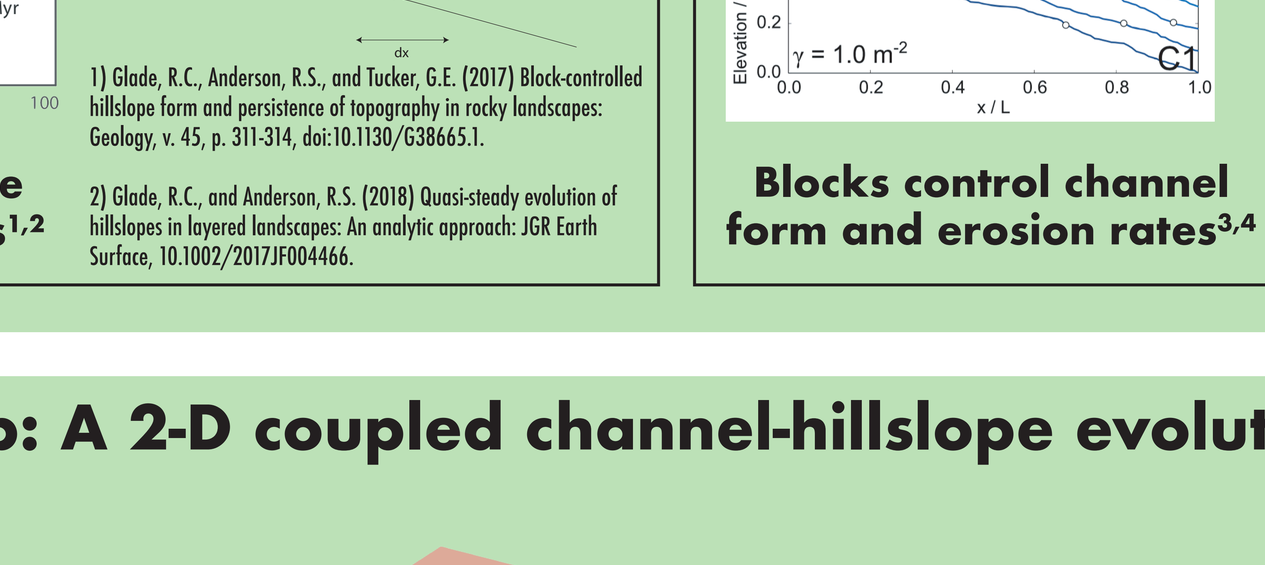
Block rules:
-Block degradation
$dD/dt = -k_b((\rho_w g H S - \tau_b) - \tau_c)$

-Blocks move according to force balance

3) Shobe, C.M., G.E. Tucker, and R.S. Anderson (2016) Hillslope-derived blocks retard river incision: Geophysical Research Letters, v.43, doi:10.1002/2016GL069262.

4) Shobe, C.M., G.E. Tucker, and Rossi, M.W. (in revision) Variable-threshold behavior in rivers arising from hillslope-derived blocks: JGR Earth Surface.

BlockLab: A 2-D coupled channel-hillslope evolution model



Horizontal resistant layer overlying more erodible rock

Channel reach influenced by blocks delivered from hillslope

Blocks are released, weathered and transported on hillslope. Blocks move in direction of steepest descent

Constant base level forcing of corner node