Blocks control hillslope evolution in layered landscapes

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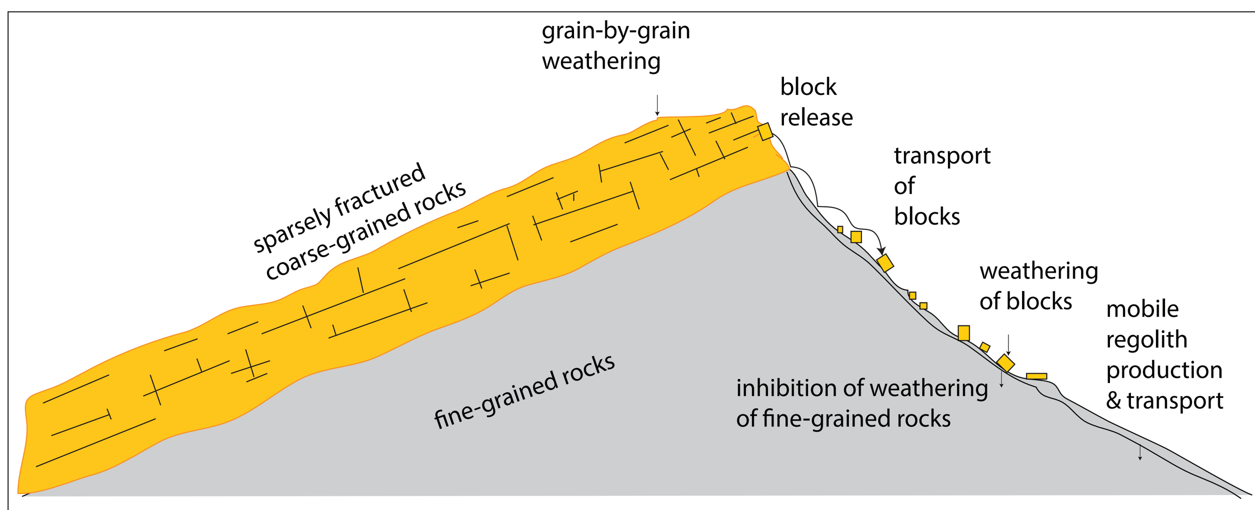
◊ How does heterogenous lithology influence hillslope evolution?
◊ Why are hogbacks concave up?
◊ What role do blocks play in persistence of topography?

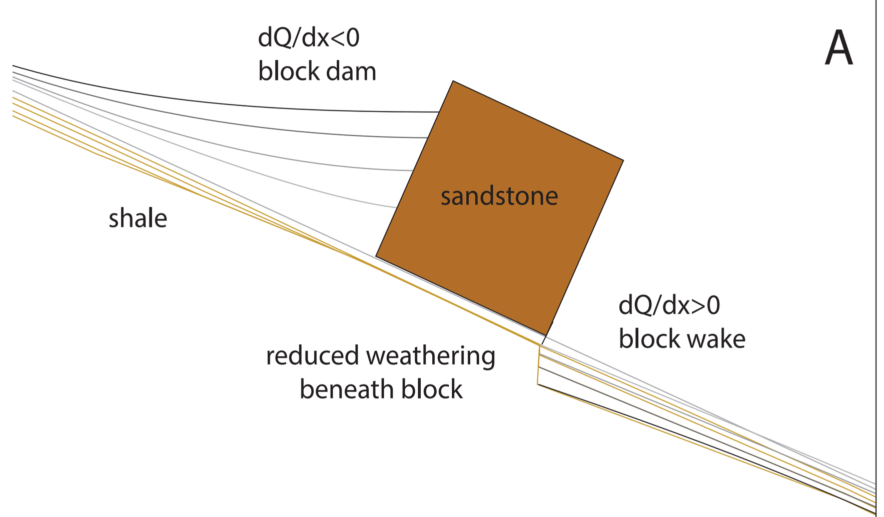


Conceptual Model:

Models of hillslope evolution require treatment of both the conversion of bedrock to soil and the subsequent transport of soil downslope. Hillslopes developed in layered rock require additional acknowledgement of block release from the resistant layer, the subsequent fate of those blocks as they move downslope, and weathering and transport interactions between blocks and underlying soft rock.

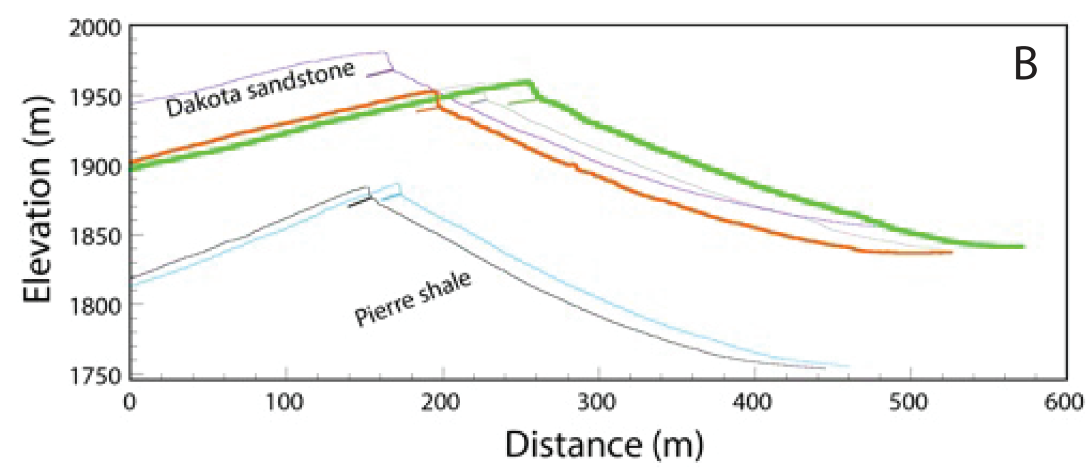
Soil Dams:

We propose that blocks of resistant rock can alter the flow of soil on blocky hillslopes (A). As soil builds up behind a block, the local slope decreases, stalling sediment transport (B). Lack of sediment supply to the base of the block results in a depression and enhanced weathering. Resistant layers on hogbacks near the Front Range tend to be undermined block-by-block as soft rock is removed from the base. Blocks are released by rotational sliding and are deposited only a short distance downslope from the scarp. However, blocks are found scattered along the full length of the ramp, much further from the scarp than they are initially deposited. This suggests that blocks must be able to move after initial placement on the slope.

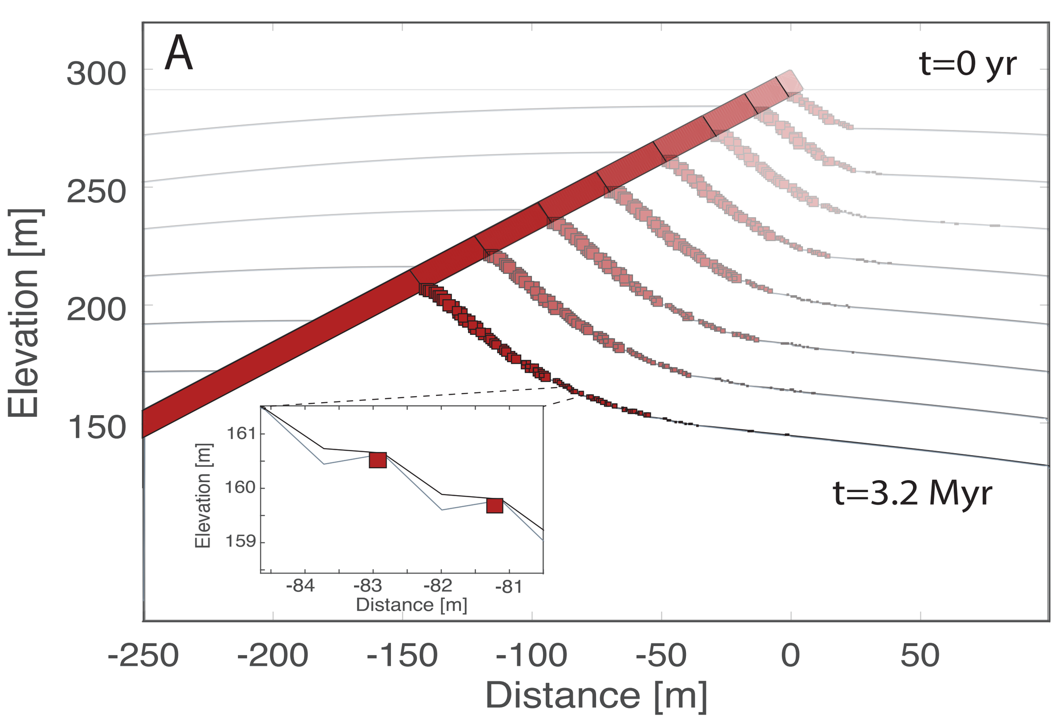


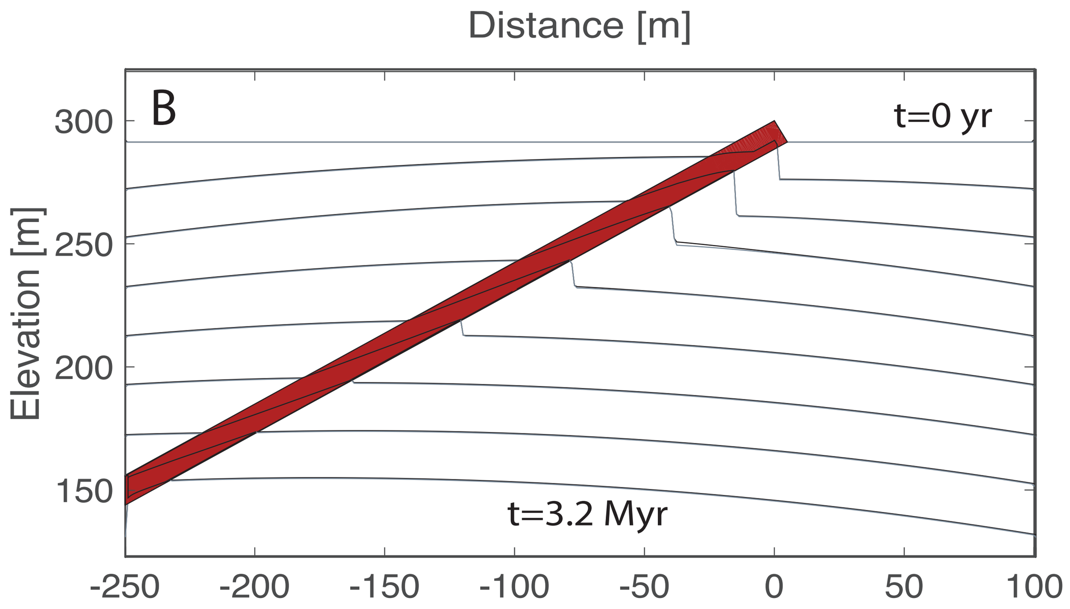
Hypotheses:

-Blocks act as soil dams that decrease sediment transport
-Blocks stochastically move into depression developed downslope
-Blocks armor underlying bedrock from weathering
-Blocks weather and decline in size through time
-These feedbacks can explain hogback evolution



A) Photo of hogback demonstrating concave slope profile B) 1-m resolution LiDAR-derived topographic profiles of hogbacks across the front range (data from Boulder Creek CZO) C) Block-covered slope of a hogback north of Ft. Collins, Colorado. Note lack of boulders beyond the base of the slope.





A) Numerical model results over time. Red squares repesent location and size of blocks. Inset shows examples of soil dam produced in model. Model reaches quasi-steady state with parallel slope retreat and steady slope profile. B) Comparison with control run with no blocks shows that blocks produce ~60 meters of relief and concave slopes.

Model Development:

◊Marries continuum and discrete approaches

◊Depth/slope dependent soil flux (Johnstone and Hilley 2014)

$$q = -kSh_*\left(1 - e^{-\frac{H}{h_*}}\right)$$

where k= hillslope efficiency [L/T], S=slope, h_*=characteristic transport depth, H=soil depth

◊Exponential weathering rule (Heimsath et al. 1997)

$$w = w_0 e^{-H/H_w}$$

where w=weathering rate [L/T]maximum weathering rate (specific to lithology), H_w=characteristic weathering depth

◊Blocks are released and deposited at top of slope when relief between resistant layer and slope becomes sufficient

$$z(r) - z(s) = D/\sin\beta$$

where z(r) is the elevation of the base of the resistant layer, z(s) is the elevation of the shale slope immediately beneath the resistant layer, D is the thickness of a block (or the distance between joints) and β is the dip of the resistant layer

◊Binary block rule: a cell either has a block or no block

◊Resistant blocks weather vertically and move over time, and are tracked discretely

◊Constant incision at boundaries

Analytical Solution:

Steady state hillslope form requires that slope increase linearly away from the divide, such that:

$$q = -kS = wx$$

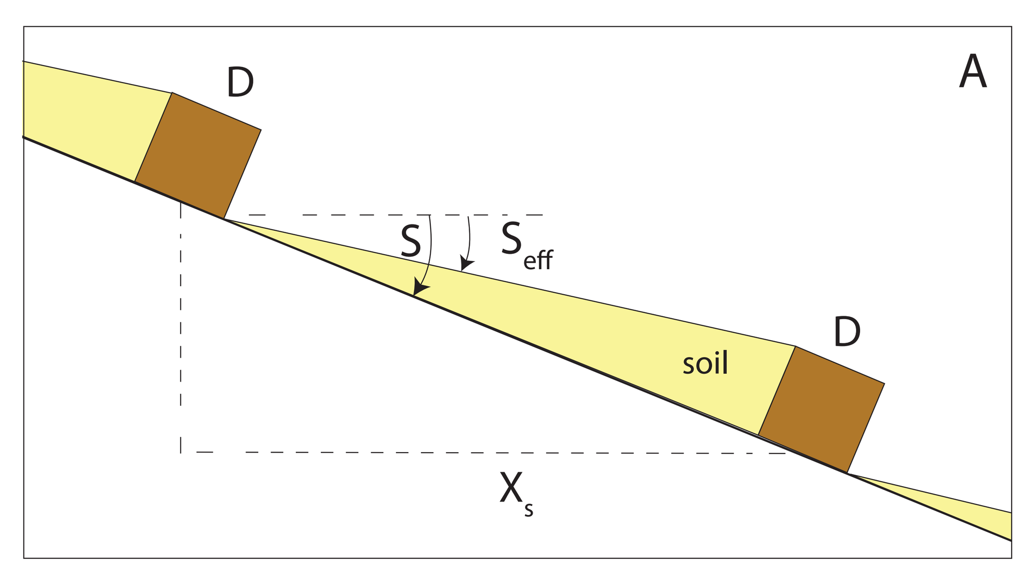
In the presence of soil dams, the effective slope is lower than the average slope S by an amount proportional to block diameter D and block spacing x_s:

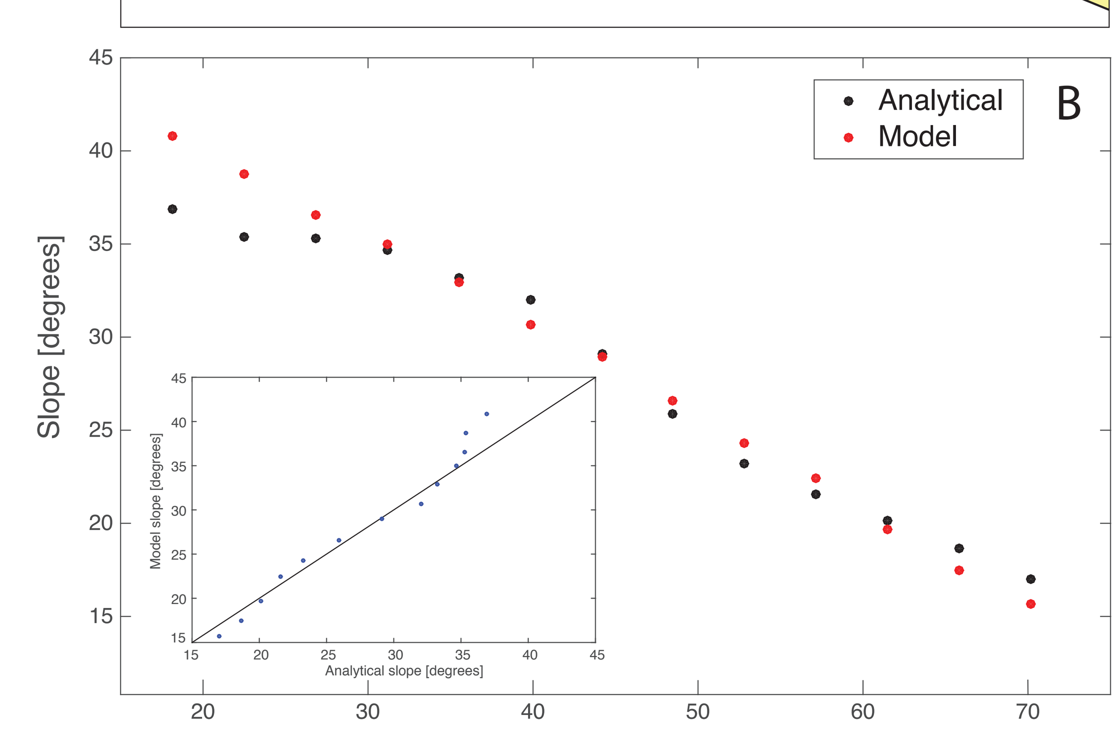
$$S_{eff} = S - \frac{D}{Xs}$$

At steady state, average slope must be:

$$S = \frac{wx}{k} + \frac{D}{Xs}$$

which produces a concave slope with blocks that decrease in size and/or increase in spacing downslope.

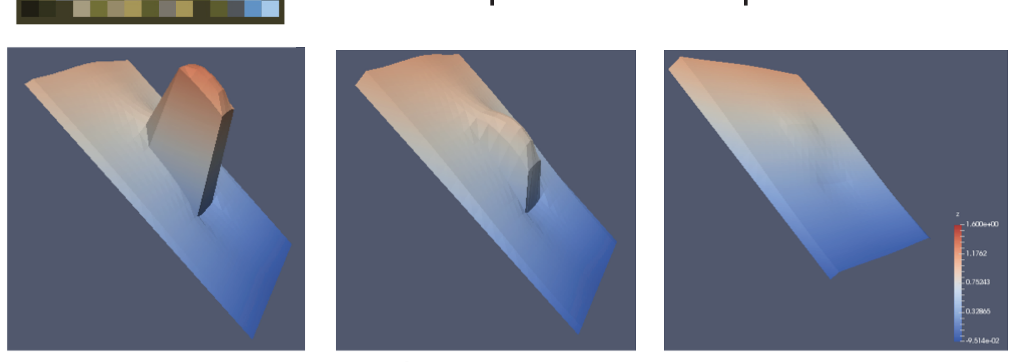




A) Conceptual diagram of rationale behind analytical solution. Effective slope relevant for local sediment transport, Seff, is lower than the average slope, S. B) Comparison of model with analytic solution. Slopes monotonically and roughly linearly decline with distance downslope. Inset compares the numerical and analytic slopes (line is 1:1 fit). Both analytical and numerically modeled slopes are reported as averages over 10 m increments, and are averaged over the last 1.2 million years, during which the model is in quasi-steady state.

Next Steps:

◊ 2D modeling in Landlab
◊ Mesas, dikes, flatirons, multiple layers
◊ Coupling with fluvial incision model
◊ Landscape scale hillslope evolution



2D numerical model of a soil dam over time. A resistant block weathers more slowly than the underlying soft rock. A depression develops downslope of the block, and soil builds up behind. Once the block completely weathers, the dammed soil is released and fills in the depression.

Flatirons, Boulder, Colorado

Sandstone mesas overlying shale near Hanskville, Utah

Vertical basalt dike embedded in shale in Shiprock, New Mexico

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