# River canyon evolution governed by autogenic channel-hillslope feedbacks

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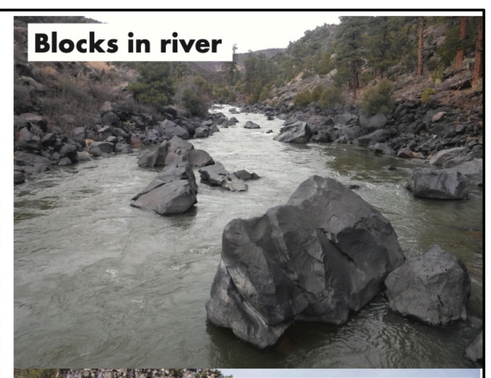
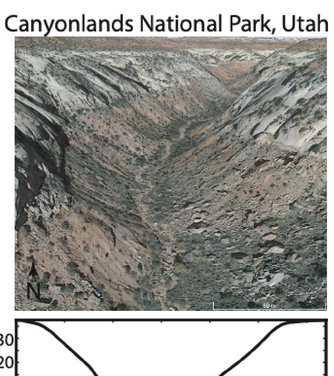
## Abstract

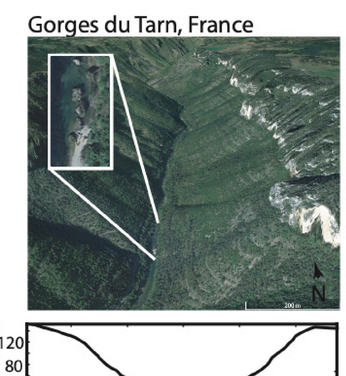
Geologists frequently debate the origin of iconic river canyons, as well as the extent to which river canyons record climatic and tectonic signals. Fluvial and hillslope processes work in concert to control canyon evolution; rivers both set the boundary conditions for adjoining hillslopes and respond to delivery of hillslope-derived sediment. But what happens when canyon walls deliver boulders that are too large for a river to carry? Large blocks of rock derived from resistant hillslope strata have recently been shown to control the evolution of hillslopes and channels by inhibiting sediment transport and bedrock erosion. Here we present Blocklab, a 2-D model within the Landlab modeling toolkit that uses a hybrid discrete-continuum framework to track block transport throughout a river canyon landscape in horizontally layered rock. Our model reveals that internal negative channel-hillslope feedbacks control erosion dynamics and result in characteristic planview and cross-sectional river canyon forms. Surprisingly, while the presence of blocks in the channel initially slows incision rates, the subsequent removal of blocks from the oversteepened channel substantially increases incision rates. This interplay between channel and hillslope dynamics results in highly variable long-term erosion rates. These autogenic feedbacks can mask external signals, such as changes in rock uplift rate, complicating the interpretation of landscape morphology and erosion histories.

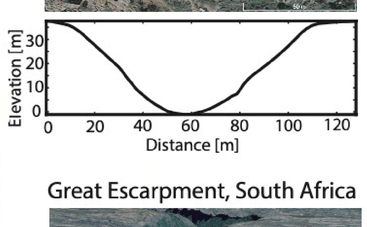



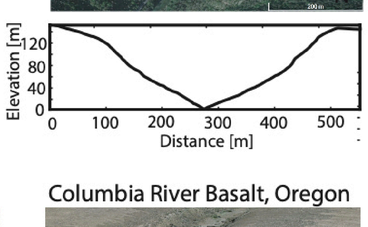


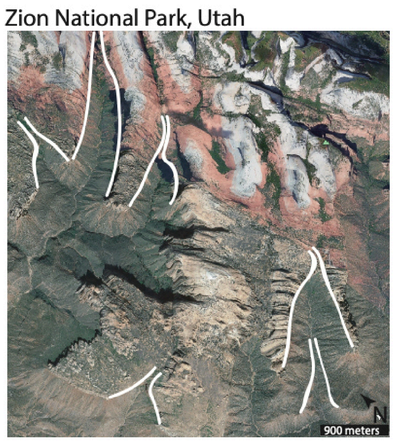
## PLANVIEW AND CROSS-SECTIONAL MORPHOLOGY

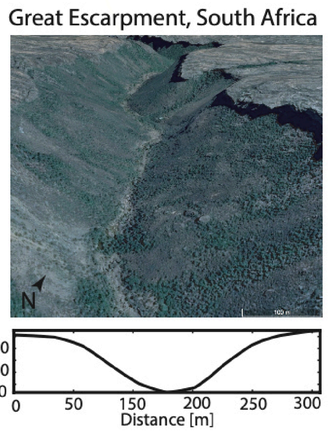



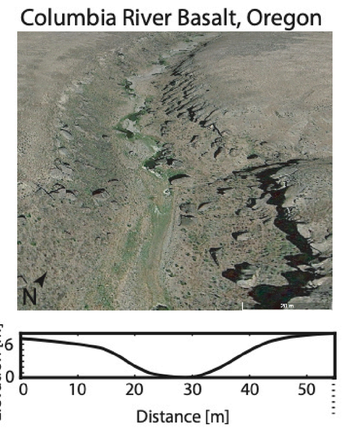



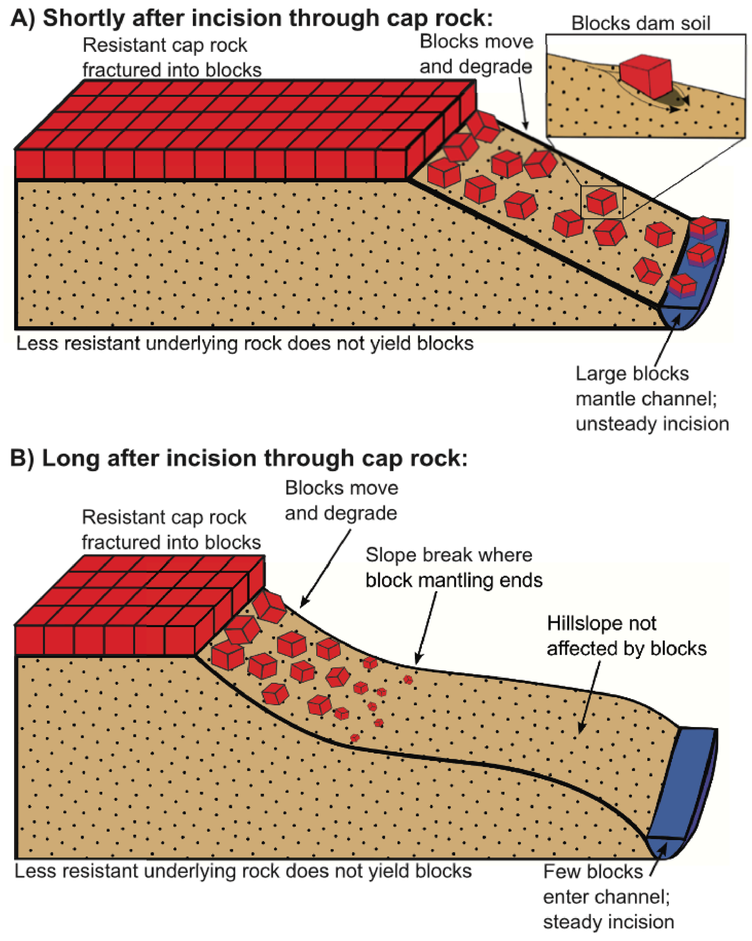



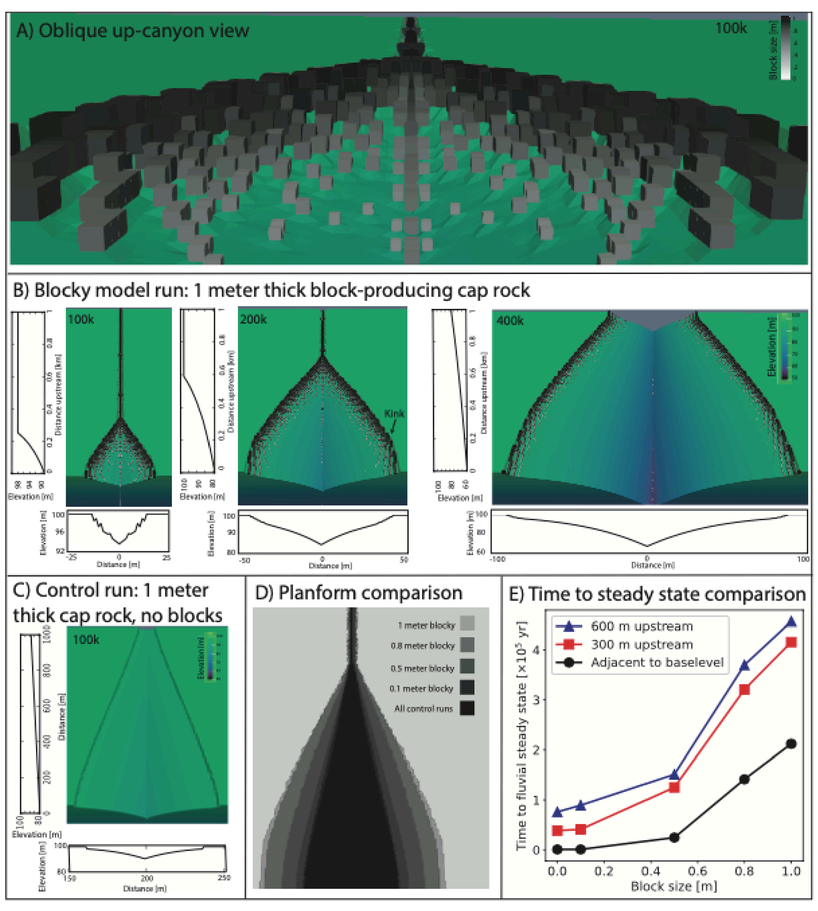




## CONCEPTUAL MODEL




**Conceptual model of canyon evolution in layered rock. A: When the cap rock is close enough to the channel to deliver large, erosion-inhibiting grains, canyon evolution is governed by interactions between unsteady channel and hillslope evolution, even when base-level forcing is steady in time. Reduction of soil transport by blocks (inset) strongly influences hillslope form, yielding linear to concave-up hill- slope profiles. B: Once the cap rock has retreated far enough from the channel that blocks no longer in- hibit incision upon arrival in the channel, the river incises at a steady rate (as- suming a steady forcing), and channel-adjacent portions of the hillslope become convex-upward.**

## NUMERICAL MODEL: MORPHOLOGY




**Model output of a river canyon incised into horizontal layered rock.**

**A: Close-up view of model at 100,000 yr. Blocks in the channel are often larger than those on the hillslope, illustrating that they were transported from farther upstream.**

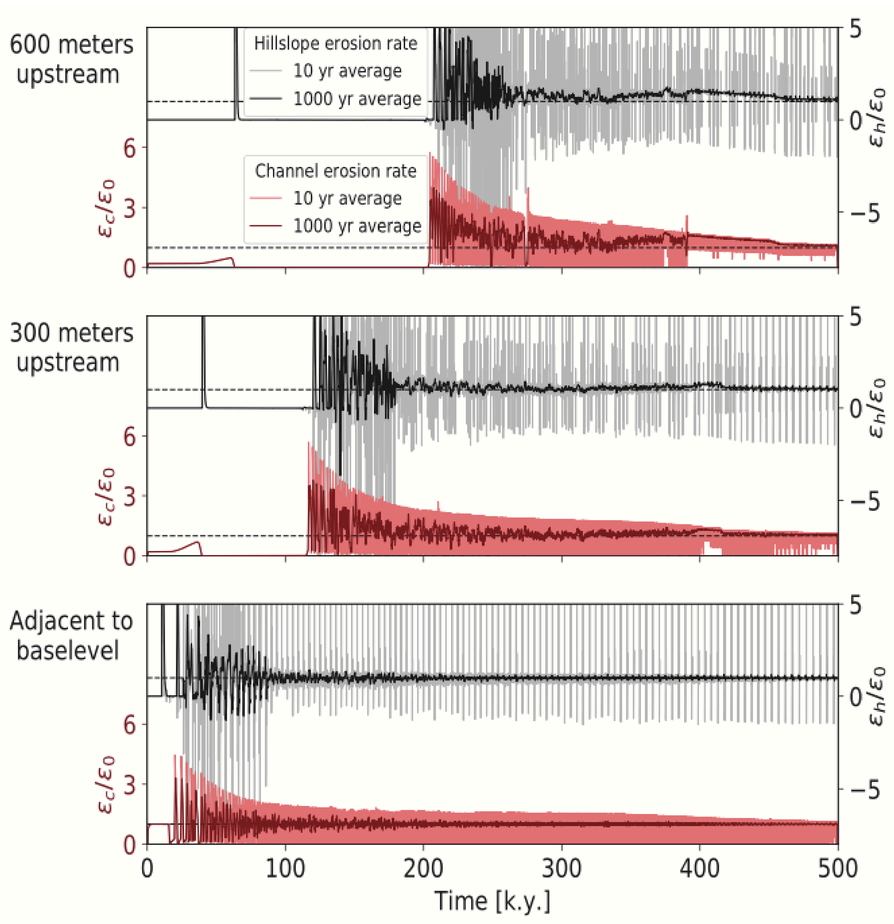
**B: Time series of model canyon evolution at 100 k.y., 200 k.y., and 400 k.y. Vertical plots on the left show channel profiles. Horizontal plots on the bottom show cross-section profiles 150 m upstream.**

**C: Control run with 1-m-thick cap rock with no blocks shown at 100 k.y.**

**D: Comparison of planform shapes for four blocky and four control model runs, Models are shown at the equivalent stage of fluvial response to base-level fall, not at the same absolute time.**

**E: Comparison of time to steady-state (1000 yr averaged erosion rates deviate by <10% from imposed base-level fall rate) fluvial incision for runs with different block sizes.**

## NUMERICAL MODEL: EROSION RATES




**Erosion rates at three points along a channel (red) and on an adjacent hillslope (black) through time. Pink and gray lines are 10 yr averaged erosion rates; red and black lines are 1000 yr averaged rates. εc and εh are the channel and hillslope erosion rates, respectively.**

**Block delivery feedbacks delay the upstream propagation of the base-level fall signal by ~100 k.y. over no-blocks response time. Once erosion commences in the channel and on an adjacent hillslope, two-way block delivery feedbacks cause 1000 yr erosion rates to deviate significantly (~4×) from imposed base-level fall rate. Feedbacks lengthen the response time of channel and hillslopes to base-level perturbation.**

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**Canyon shape and erosion dynamics governed by channel-hillslope feedbacks**

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# For more info

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