Downstream sweep erosion as a mechanism for bedrock valley widening: comparison between model simulations and field examples

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We use a newly-developed lateral erosion component in the Landlab modeling frame work to explore how model results compare with recently published field examples of downstream sweep erosion as a mechanism for gorge eradication and bedrock valley widening.

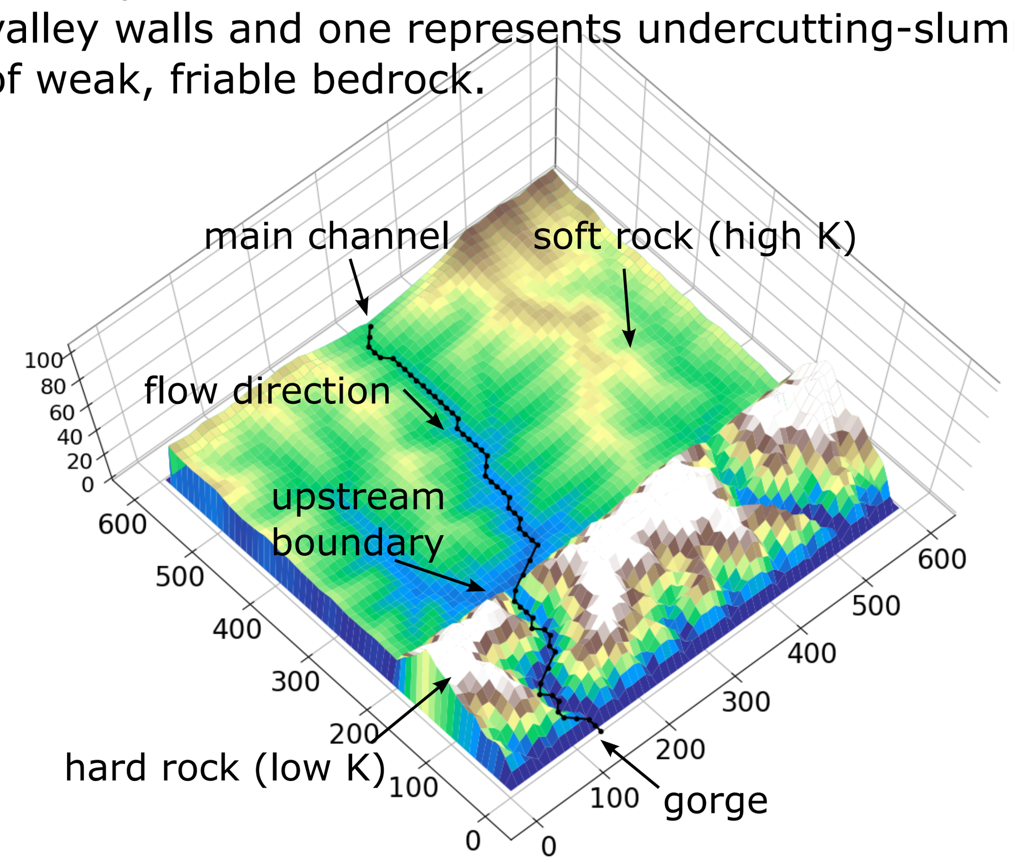
Lateral Erosion: We hypothesize that lateral erosion rates depend on stream power exerted on the channel walls created by centripetal acceleration in a stream bend.

This is expressed as *centripetal stream power:* $\omega_c = \frac{\rho g Q S}{r_c F}$

Lateral erosion rate is given by: $E_l = K_l \frac{AS}{r_c}$

Model Setup: Two different values of bedrock erodibility (K) give rise to a broad upstream valley with a mobile channel and a narrow downstream gorge (see figure below of model domain before lateral erosion).

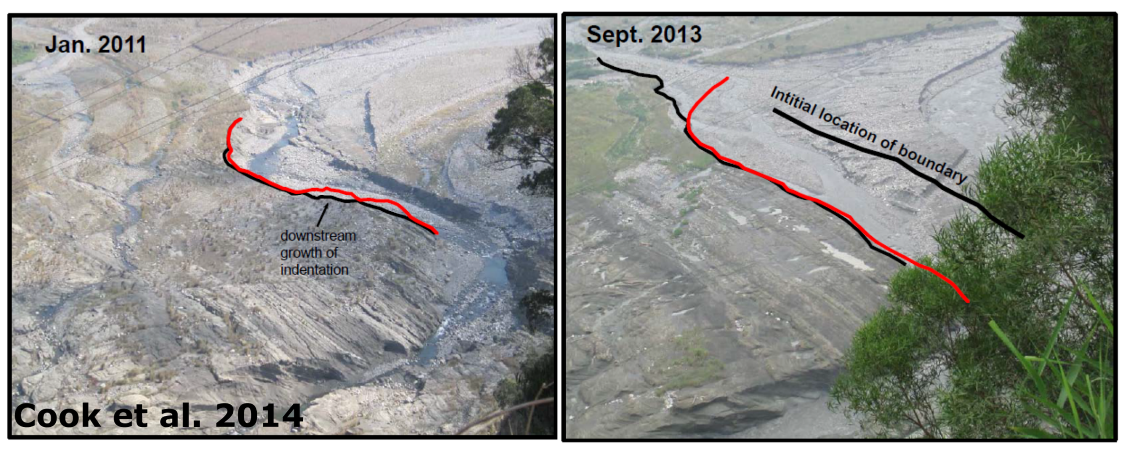
Two formulations of the lateral erosion model were used. One represents erosion of massive, resistant bedrock valley walls and one represents undercutting-slumping of weak, friable bedrock.



Downstream sweep erosion: field example

Cook et al. 2014 proposed downstream sweep erosion (DSE) as a mechanism for gorge eradication. DSE is the propagation of a wide erosion front where a broad upstream valley meets a narrow gorge.

Predictions from Cook et al. 2014:
1. DSE erosion of upper gorge boundary that occurs when the channel makes a sharp bend to enter the gorge.
2. Preferential erosion of promontories and bends within the gorge and little erosion of walls in straight sections.
3. Decreasing sinuosity with time



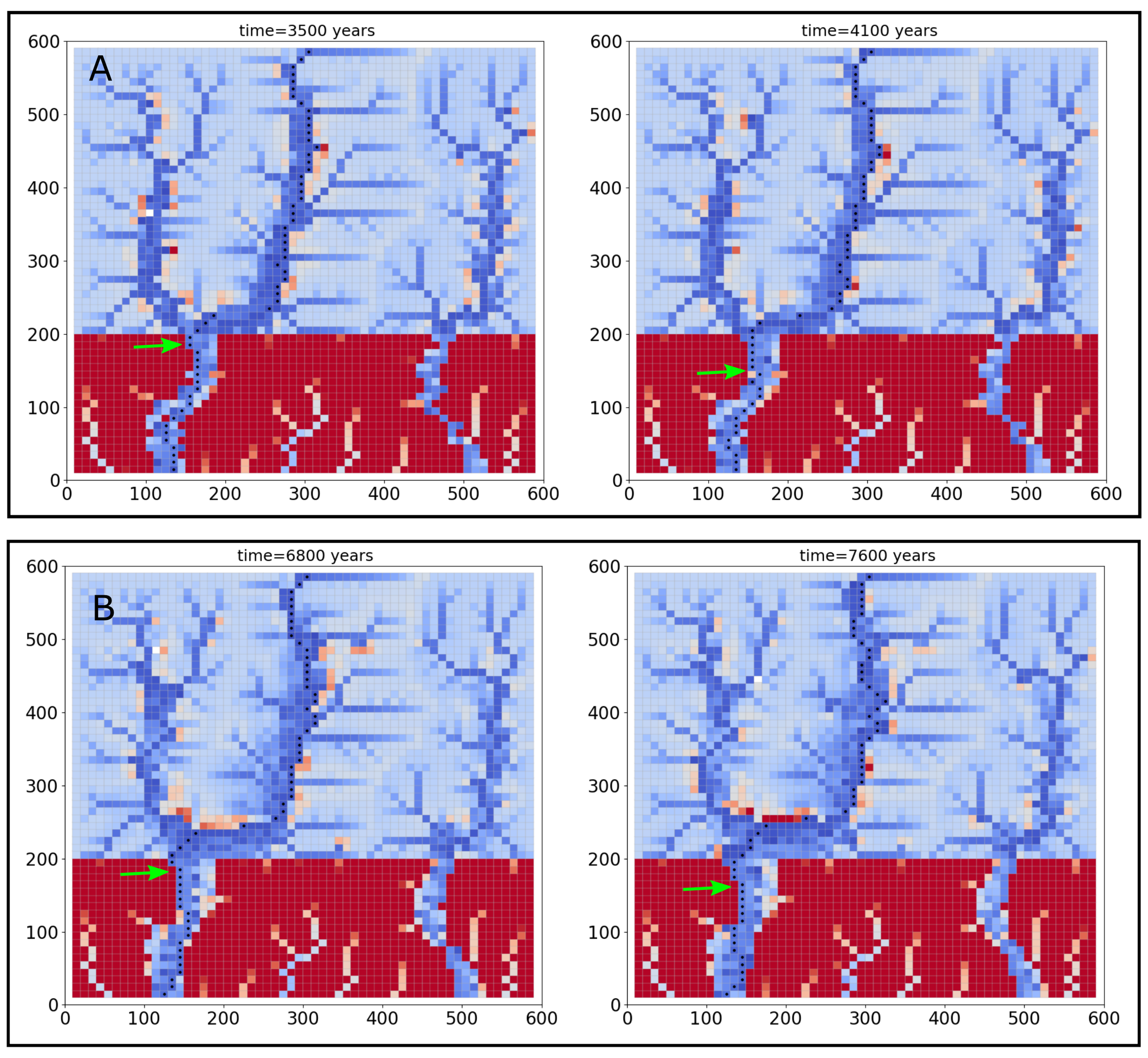
Cook et al. (2014) documented DSE in the Daan River gorge in Taiwan. Black and red lines show current and previous position of bedrock boundary. They documented ~85 m of bedrock erosion in 4 years. January 2011, localized erosion at the boundary, creating a recessed bend. Erosion on the downstream side of this bend results in further bedrock erosion.

Downstream sweep erosion: model examples

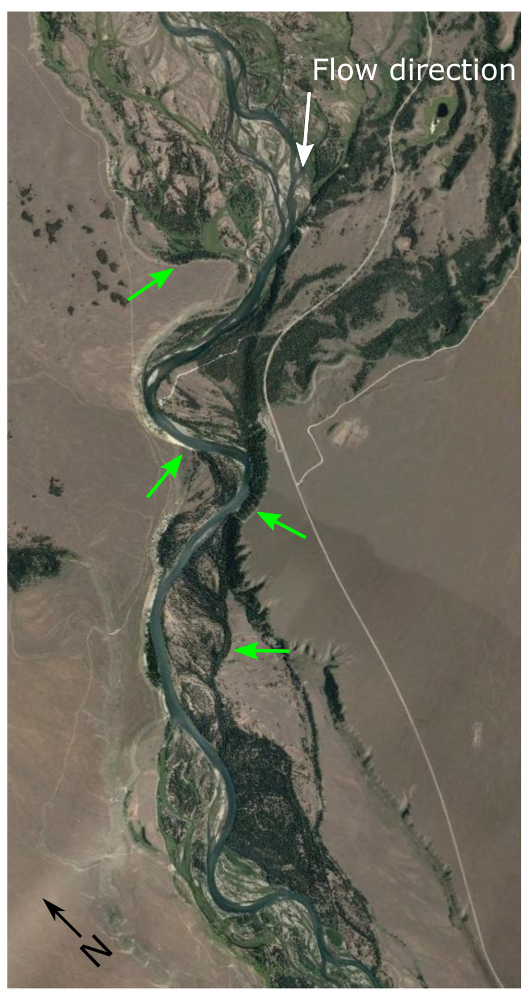
Blue and white indicate areas where slopes are characteristic of fluvial channels, red indicates areas where slopes are characteristic of hillslopes.

Undercutting slump model with two phases of DSE in panels A, B. Green arrows indicate location of eroding boundary, black dots indicate channel position.

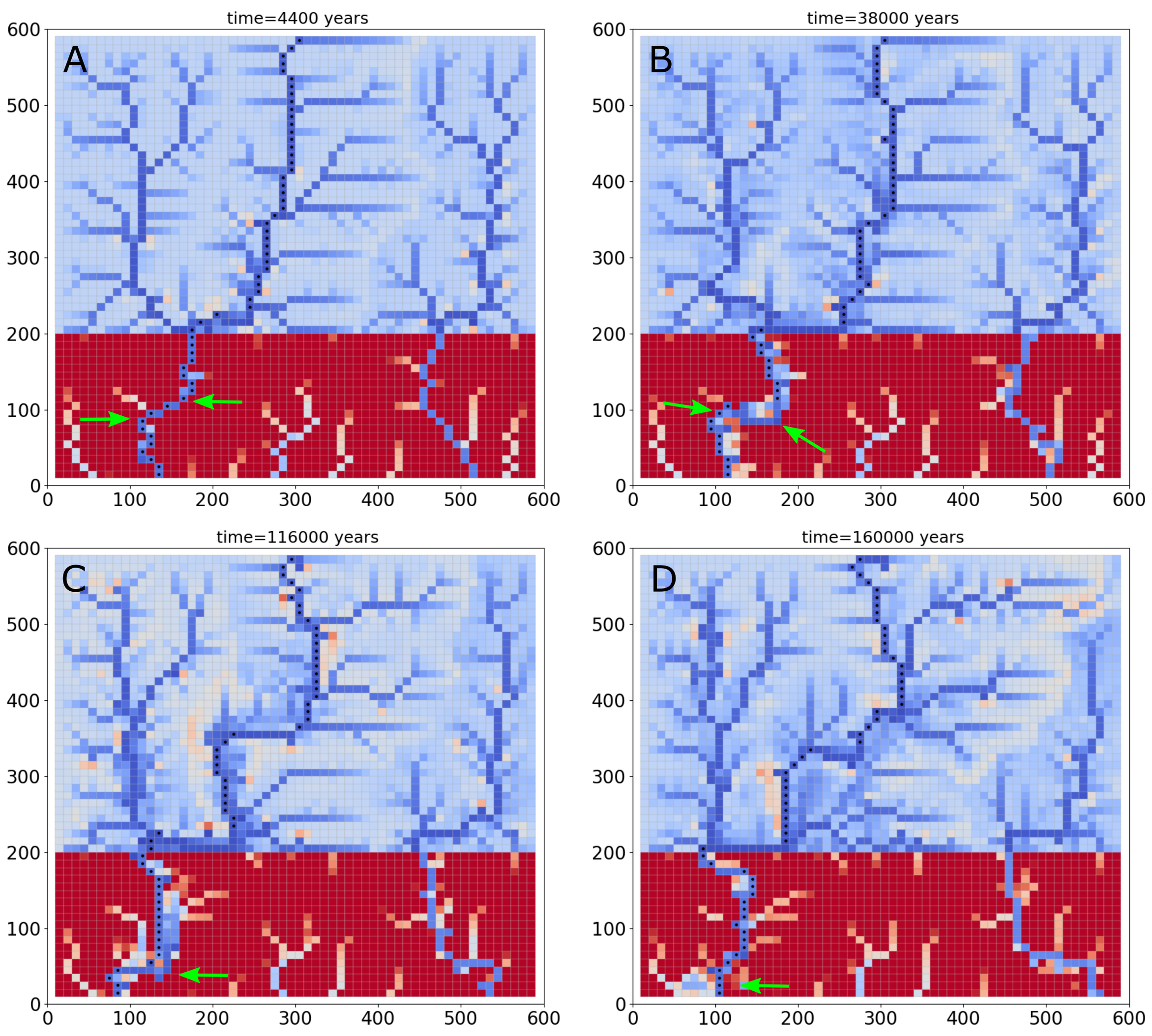
The channel attacks the upstream boundary of the gorge, resulting in rapid, successive downstream erosion and valley widening. The valley widens from 30 m to its maximum width of 70 meters, in ~4000 model years. Note decreased sinuosity in the gorge over time.



Preferential erosion in bends and downstream meander migration



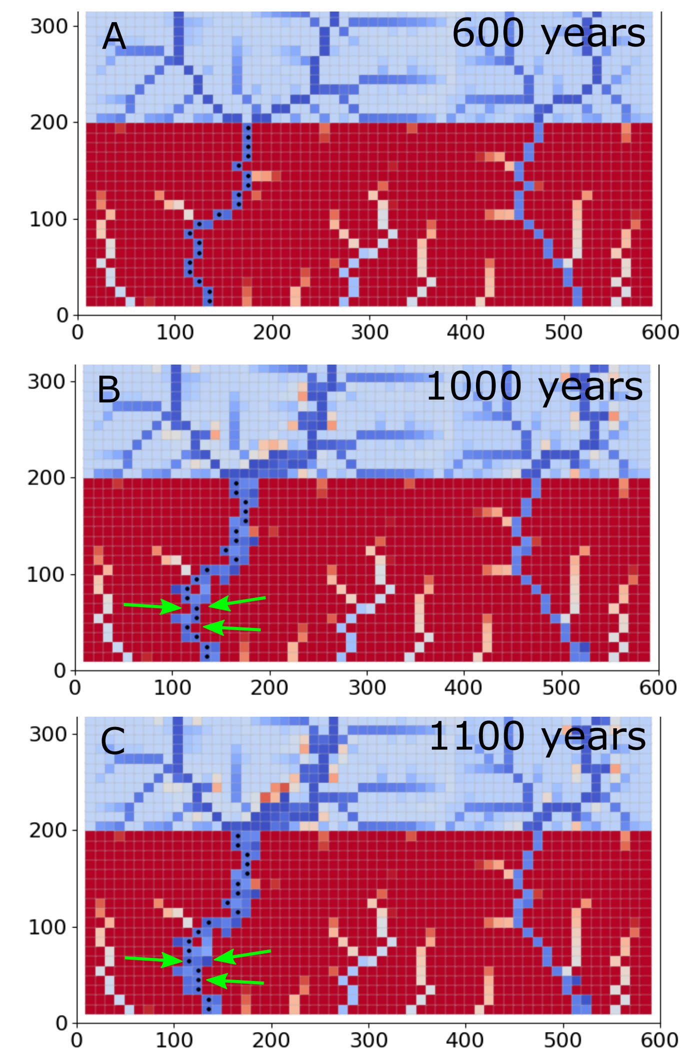
Example of possible current and past DSE of terraces on the Snake River, Grand Teton NP. Terraces erode on downstream sections of bends and meanders migrate downstream.



The model predicts that bends within the gorge should have high lateral erosion rates and sweep downstream. Total block erosion models show meander growth and downstream migration, indicated by green arrows.

A. Sinuous gorge begins to widen.
B. Downstream and outward growth of meanders.
C-D. Meander migrates towards the edge of the model and is eradicated by 160ky.

Preferential erosion of promontories in gorge



Undercutting-slump models showing preferential erosion of bedrock promontories that stick out into the channel.

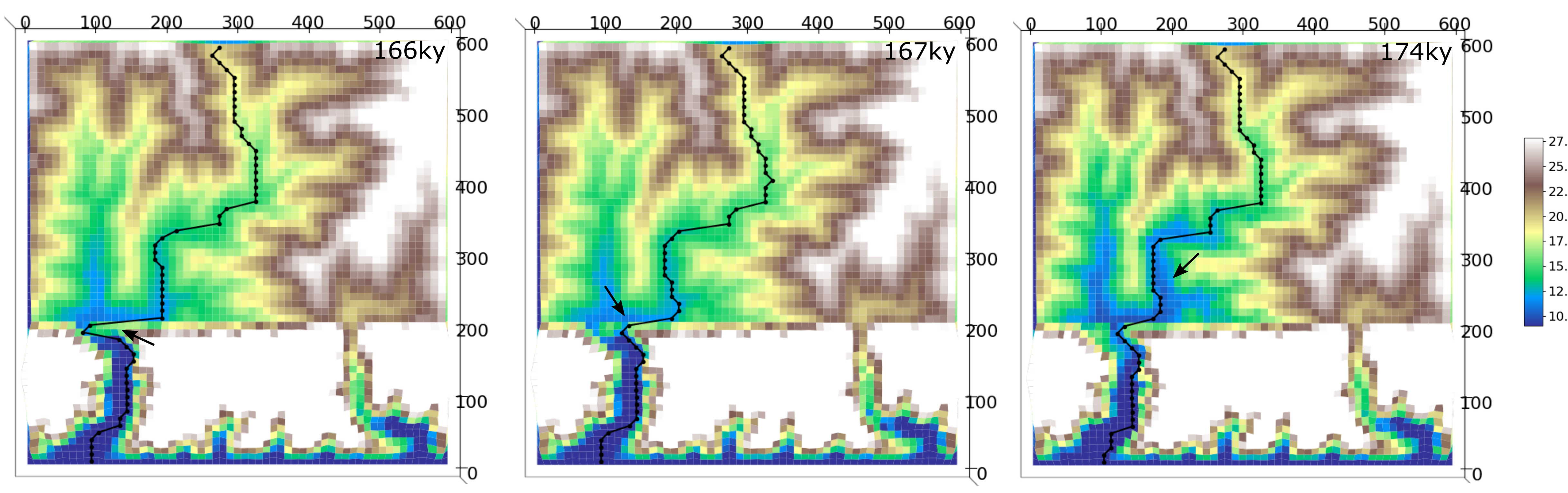
A. Gorge before any widening. Channel position shown with black dots
B. 1,000 years into the model, with channel widening. Green arrows point to three promontories in the gorge.
C. In 100 years of model time, the three promontories were eroded, widening the channel by 10-20 meters.

This bedrock promontory in the Daan River gorge collapsed along a bedding plane during a single flood event in 2012. In this location, lateral erosion occurs from undercutting and subsequent wall collapse (Cook et al. 2014)

Thin "knife blade" ridge in models and field examples

The total block erosion model shows the development of an unusual feature, a thin "knife blade ridge", at the entrance to the gorge, which is also found in some locations where DSE is thought to be a primary erosive mechanism. Notable features are indicated with black arrows on the elevation figures below.

A. Formation of a thin "knife blade" ridge at the entrance to the gorge diverts flow around the ridge. Erosion is focused on the boundary where the channel makes a 90° angle against the high relief rock.
B. At 167ky, the channel erodes through the ridge taking a more direct path through the gorge.
C. Following the breakthrough of the ridge, the channel upstream of the gorge incises.



knife blade ridge — erosion through ridge — upstream incision

A bedrock gorge holds a tributary to the main channel. A thin "knife blade" ridge remains between the broad upstream channel and the main river. The near vertical face on the upstream side and sloping on the downstream side suggests the ridge is being eroded from upstream.

References: Cook, K.L., J.M. Turowski, and N. Hovius (2014), River gorge eradication by downstream sweep erosion, *Nature Geoscience*, 7 (9), 682-686, doi:10.1038/NGEO2224.