Preservation timescales of fluvial strath terraces

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Abstract

Ubiquitous in terrestrial landscapes, river terraces are often interpreted to record stream response to perturbations such as sea level change [1], and regional climate transitions [2] and tectonic uplift [3]. Conversely, a river exercising a constant vertical erosion rate could generate terraces if able to migrate laterally [4]. Though it has received little attention in the past, this last mechanism requires no change in forcing of the fluvial system and represents a logical null hypothesis for terrace formation.

I employ a geometric model to evaluate how competing erosion regimes influence terrace lifetimes. In the model, a fixed-width channel belt migrates due to prescribed lateral and vertical erosion rates. A baseline scenario of constant-magnitude lateral and vertical erosion rates is punctuated by brief erosion rate excursions due to a generic pulse in forcing. By varying the erosion rates and the frequency of pulses in forcing, the model will be used to assess the required frequency of perturbations to overcome terrace erasure by lateral stream erosion.

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Figure 1. River terraces on the Snake River, Wyoming (left, in background), and near Uzboi Vallis, Mars (right). Terraces are widespread in terrestrial landscapes and may hold clues to past climate and tectonics.

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Motivation

A fluvial strath terrace is a beveled bedrock surface capped with a veneer of alluvium, and represents an abandoned channel bottom. Strath terraces can record fluvial activity tens of thousands of years in the past. The topographic step represented by a terrace is often interpreted to record marked changes in controlling parameters such as discharge, sediment supply and base level. Because terraces are ubiquitous on Earth and even noted adjacent to outflow channels on Mars (Fig. 1), understanding their genesis holds implications for the geologic interpretation of numerous landscapes.

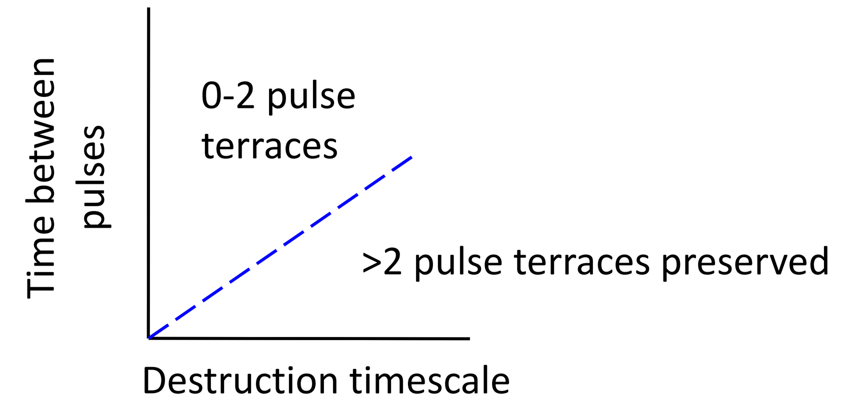
The mechanics of strath terrace formation remain poorly understood. For example, investigators frequently interpret the alluvium above the strath to aid in strath carving, yet capping alluvium may reach a thickness prohibitive for bed incision. In words that remain broadly influential, Gilbert [4] suggested that strath terraces record changes in the ratio of lateral to vertical incision of bedrock due to changes in the amount of coarse sediment armoring the bed. A period of high sediment load limits vertical incision while the stream to erodes laterally against the channel walls to form an extensive bedrock platform; as sediment supply wanes, stripping of bed cover enables vertical incision and abandonment of the platform as a pair of strath terraces. Because of climate's expected impact on sediment quantity and size, strath formation has been widely attributed to climate change [e.g., 5-7]. Rapid base level change due to tectonic uplift [3] or sea level change [1] can also cause pulses of incision and strath abandonment.

One hundred years ago, Davis [8] proposed a less eventful, and underappreciated, mode of terrace generation: a river exercising a constant vertical erosion rate may generate terraces by sweeping back and forth across a valley (Fig. 5). This mechanism requires no change in forcing of the fluvial system, and thus represents the simplest explanation for terrace formation. Although mechanical models of terrace formation retain considerable uncertainty, terraces made by different mechanisms are likely to possess different geometries. Specifically, the continuous lateral and vertical erosion scenario envisioned by Davis should produce sloping, unpaired terraces, whereas event-driven mechanisms (such as pulses of incision due to tectonic uplift) are likely to produce flat, paired strath terraces.

Hypothesis

A river which sweeps across a valley can erase paired terraces generated by specific events, and occasionally leave terraces unrelated to changes in forcing. Thus terraces generated by climate change, tectonic uplift and other event-driven mechanisms should possess a characteristic preservation timescale which reflects the competition of processes which create and destroy them. When the timescale of terrace generation exceeds the timescale of valley sweeping, two or fewer pulse-related terraces should remain; in the opposite case, multiple paired, pulse-related terraces should remain (Fig. 2).

Figure 2. Theoretical prediction for preservation of terraces made by pulses of erosion due to tectonic, climate, or sea level "events."



Geometric model of valley evolution

I have developed a geometric model to evaluate how competing erosion regimes influence the lifetimes of terraces. In the model, a fixed-width channel belt migrates due to prescribed lateral and vertical erosion rates (Fig. 3). The channel belt may represent a single channel, or a braided stream. A baseline scenario of constant-magnitude lateral and vertical erosion rates is punctuated by brief erosion rate excursions due to a generic pulse in forcing. Varying the lateral and vertical erosion rates, as well as the frequency and magnitude of pulses in forcing, permits assessment of the required frequency of perturbations to overcome terrace erasure by lateral stream erosion.

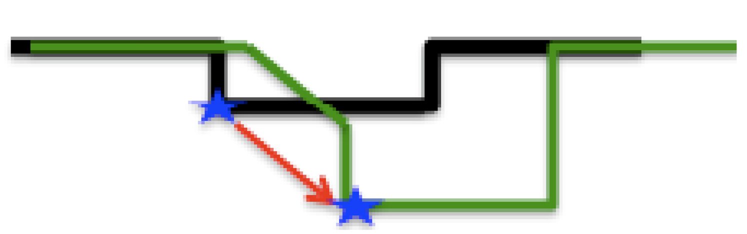


Figure 3. Schematic of model behavior. Rectangular channel migrates, and original land surface profile (black) is redrawn (green). Main model inputs are lateral and vertical erosion distances for each time step. Water in channel is omitted for ease of viewing land surface profile.

Advantages of a numerical model

In the case of steady lateral and vertical erosion, one can estimate the timescale of terrace destruction as follows:

- Formation timescale: time between pulses in forcing.
- Destruction timescale: time for river to sweep across valley. If river lateral erosion direction follows a random walk, then

Lateral distance traveled by channel in N steps $= \sqrt{N} * step$ — Where step length = horizontal erosion rate*Δt

And the destruction timescale $= \dfrac{\text{valley width}}{\text{lateral displacement rate}}$

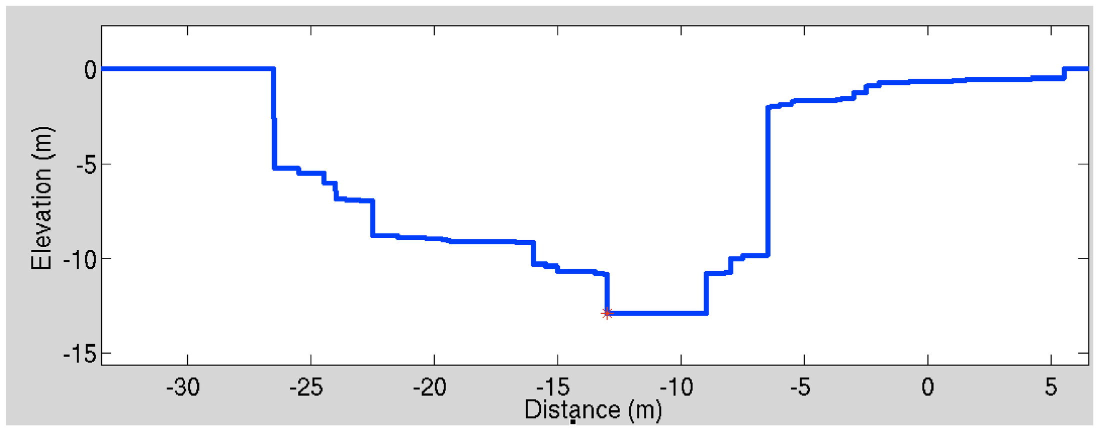
A numerical model can simulate landscape evolution under more complicated erosion conditions. In particular, it can account for:

- Interaction of different terrace formation mechanisms (i.e., terrace generation by vertical erosion in event-driven pulse, can compete with the case of steady lateral and vertical erosion).
- Feedbacks (e.g., lateral erosion rate can vary with cutbank height, a proxy for incision history).

How long do event-driven terraces persist?

Currently, I am continuing simulations at full resolution (finer than the smallest nonzero channel movement distance in one time step) and spanning relevant timescales (Fig. 4). Model results will enable mapping of the preservation zone for pulse-related terraces for different formation and erasure timescales (Fig. 2).

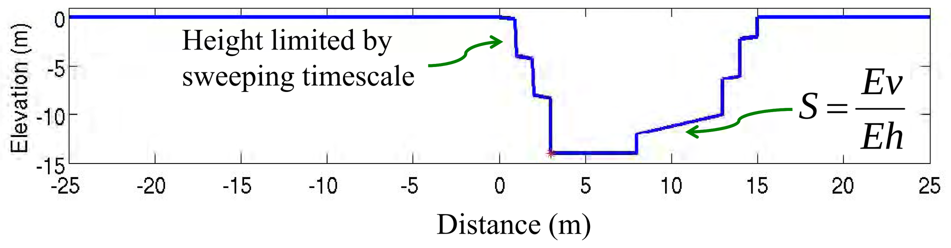
Figure 4. Example simulation with competing (pulse vs. continuous) vertical erosion regimes. Model time was 1000 yr, with 1 yr time steps. In the model, measurement of terrace slope permits discrimination between terraces formed by each erosion mechanism.



Implications for strath terrace interpretation

- Strath terraces can record climate change, but can also be destroyed in a continuous vertical erosion regime that generates terraces.
- Model results can inform interpretation of fluvial terraces via the expected lifetimes of terraces formed by either episodic or continuous vertical erosion.
- The continuous vertical erosion mechanism produces a specific bedrock interface geometry (unpaired, sloping strath terraces – Fig. 5), and future work can utilize surface (topographic) and subsurface (GPR, well logs) data to identify this process signature. Identifying terraces formed by this background mechanism is essential to tell if a terrace records a unique geologic event.

Figure 5. Sloping terraces carved during continuous lateral and vertical erosion record the extent of the mechanism and potentially the ratio of erosion rates – a major unknown in studies of bedrock river evolution.



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Acknowledgments

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