

# Predictions of Autogenic Fluvial Terraces and Comparison to Climate Change Expectations\*

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## Abstract

Terraces eroded in sediment (cut-fill) and bedrock (strath) preserve a geomorphic record of river activity. River terraces are often thought to form when a river switches from a period of low vertical incision rates and valley widening to high vertical incision rates and terrace abandonment. Consequently, terraces are frequently interpreted to reflect landscape response to changing external drivers, including tectonics, sea-level, and most commonly, climate. In contrast, unsteady lateral migration in meandering rivers may generate river terraces even under constant vertical incision and without changes in external forcing. To explore this latter mechanism, we use a numerical model and an automated terrace detection algorithm to simulate landscape evolution by a vertically incising, meandering river and isolate the age and geometric fingerprints of intrinsically generated river terraces. Simulations indicate that terraces form for a wide range of lateral and vertical incision rates. Terrace formation is limited by a characteristic timescale for relief generation, and once this is surpassed the time interval between terraces increases in time due to re-working of previously visited areas. Surprisingly, intrinsically generated terraces are commonly paired and longitudinally extensive—attributes that are thought to be diagnostic of climate change. Evolving spatial differences in bank strength between bedrock and sediment reduce terrace formation frequency and length, and can explain sub-linear terrace margins at valley boundaries. Comparison of model predictions to natural river terraces indicates that long terraces are the most unique indicators of pulses of vertical incision, and may contain the imprint of past climate change on landscapes.

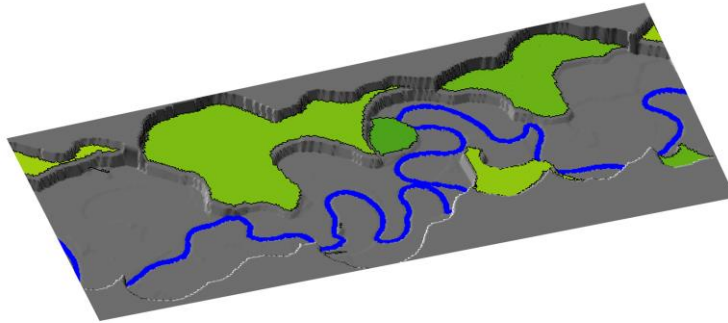
## References Cited

Hancock, G.S., R.S. Anderson, O.A. Chadwick, and R.C. Finkel, 1999, Dating fluvial terraces with <sup>10</sup>Be and <sup>26</sup>Al profiles: Application to the Wind River, Wyoming: *Geomorphology*, v. 27, p. 41–60.

Howard, A.D., and T.R., Knutson, 1984, Sufficient conditions for river meandering: A simulation approach: *Water Resources Research*, v. 20, p. 1659–1667.

Limaye, A.B., and M.P. Lamb, 2015 (in review), Numerical model predictions of intrinsically generated fluvial terraces and comparison to climate-change expectations: *Journal of Geophysical Research - Earth Surface*.

# Predictions of autogenic fluvial terraces and comparison to climate change expectations



**Ajay B. Limaye\* and Michael P. Lamb**

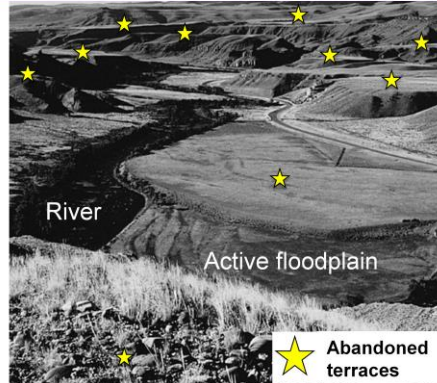
California Institute of Technology

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**River terraces are globally distributed markers of channel evolution over millennial timescales.**



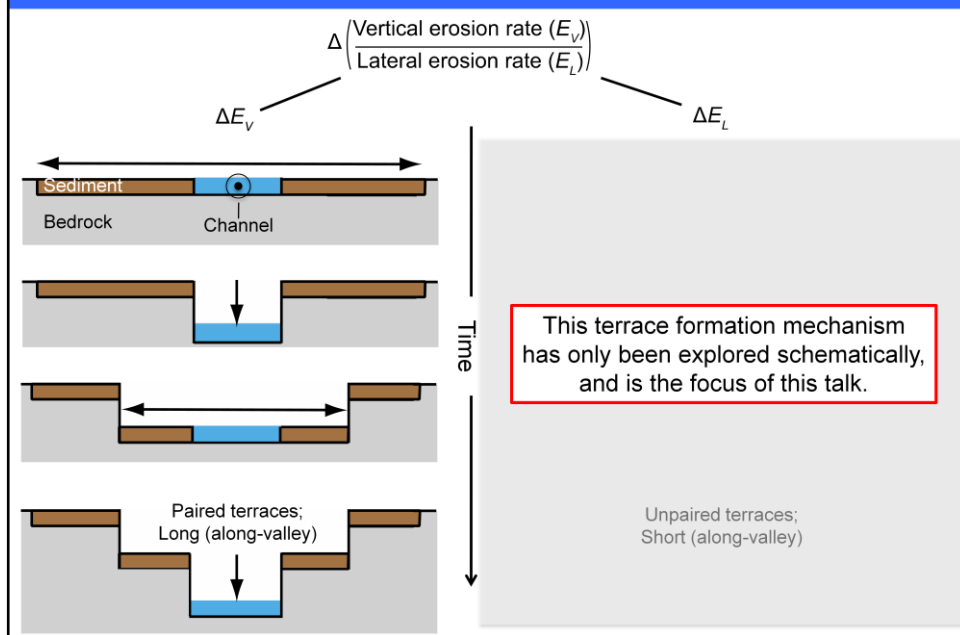
Fill terrace  
San Gabriel River valley, California



Strath (bedrock) terraces  
Wind River valley, Wyoming  
(Hancock *et al.*, 1999)

**Both terrace types are often interpreted to form when climate change drives cycles of vertical incision.**

## Terrace formation requires a change in the ratio of river vertical erosion to lateral erosion.



Presenter's notes: We don't even know whether these hypotheses are geometrically plausible.

## Motivating questions

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1. How often does unsteady lateral erosion make autogenic terraces, without pulses of vertical incision?
2. How can autogenic terraces be distinguished from those that record climate change?

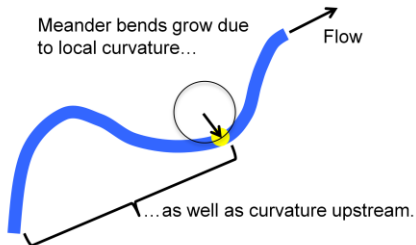
## Outline

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1. Numerical model for a river that erodes vertically and laterally.
2. Model results for the frequency of autogenic terrace formation.
3. A framework for distinguishing autogenic terraces.

**To test hypotheses for terrace formation,  
we constructed the simplest possible model that includes:**

**1. Lateral erosion.**



- This meandering model is efficient for simulations over timescales greater than 1000 years (*Howard and Knutson, 1984*)

**2. Vertical incision.**

- The vertical incision rate is directly imposed, spatially uniform, and can vary in time.

**3. An objective method for identifying terrace surfaces based on their low local relief.**



## Key model parameters

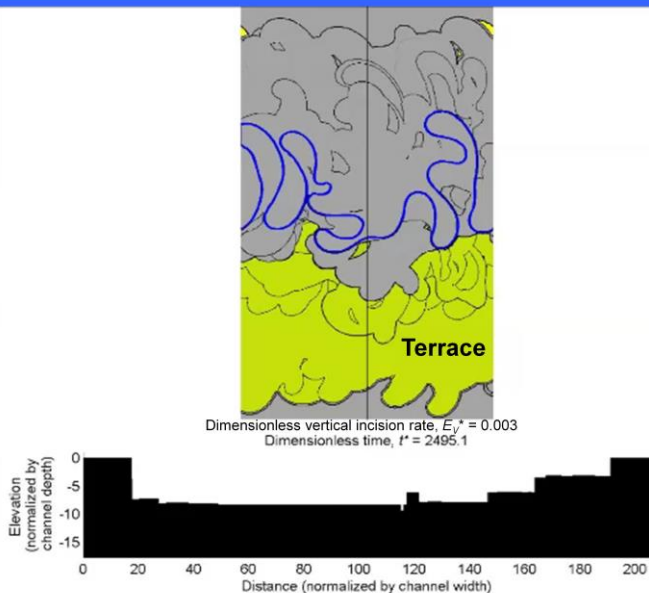
- Time ( $t$ )
- Vertical incision rate ( $E_V$ )
- Lateral erosion rate ( $E_L$ )
- Channel width ( $w_c$ ) and depth ( $h_c$ )

**We distill these variables to non-dimensional parameters including:**

$$\begin{array}{l} \text{Non-dimensional} \\ \text{vertical incision rate} \end{array} \quad E_V^* = \frac{\text{vertical erosion rate} * \text{channel width}}{\text{lateral erosion rate} * \text{channel depth}}$$

$$\begin{array}{l} \text{Non-dimensional} \\ \text{simulation time} \end{array} \quad t^* = \frac{\text{time} * \text{lateral erosion rate}}{\text{channel width}}$$

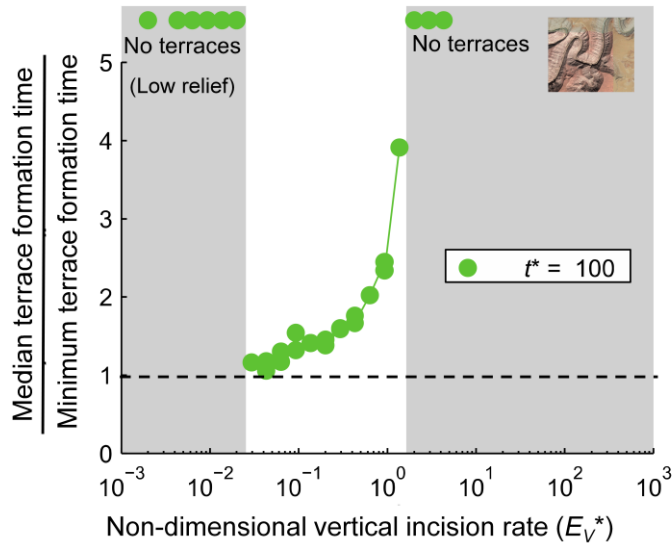
**River terraces commonly form with steady vertical incision rates due to unsteady lateral erosion.**



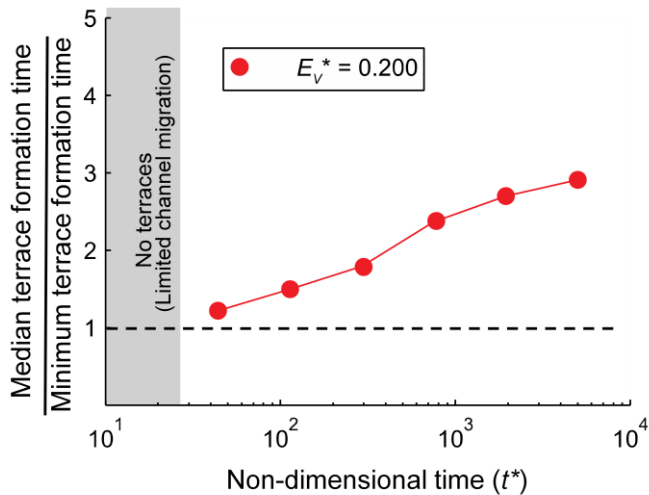
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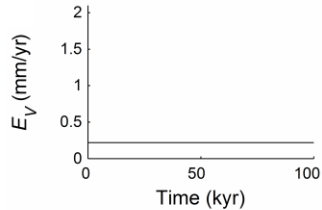
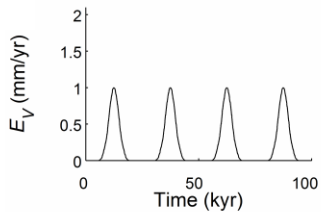
For conditions where terraces form, there is a repeating time between terrace levels set by the rate of vertical incision.



The time between terrace levels increases gradually with non-dimensional simulation time because the channel destroys existing terraces.

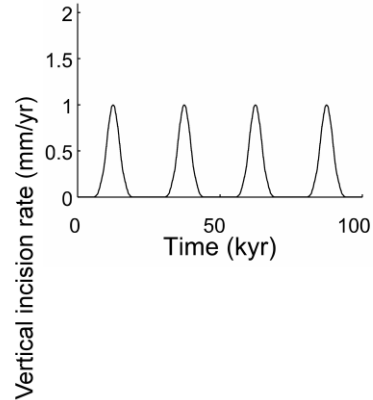
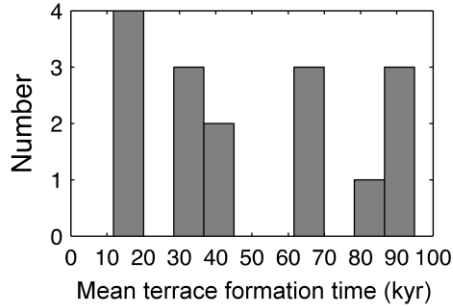


## Are autogenic terraces distinct from terraces formed by incision pulses?



Both cases: Lateral erosion rate = 1 m/yr

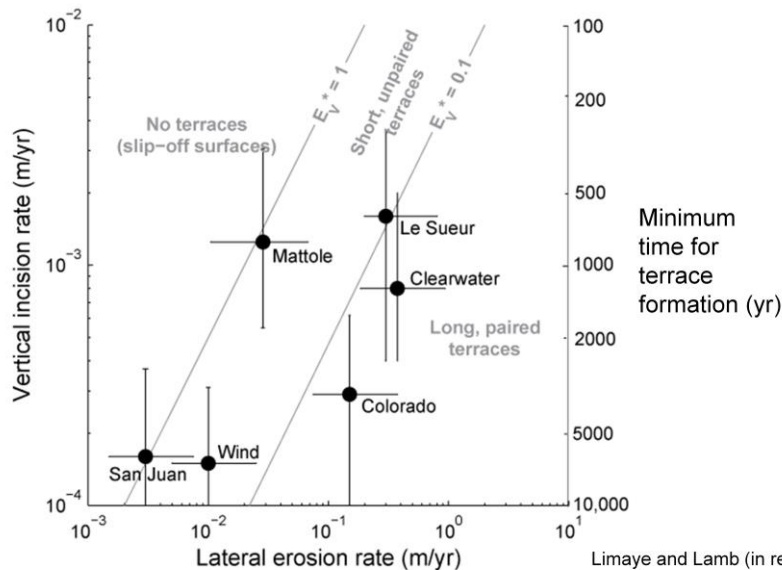
**For a constant vertical incision rate, meandering forms terraces quasi-periodically at time intervals that overlap with climate-change timescales.**



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Presenter's notes: The time intervals between unique terrace levels are consistent with meandering with constant vertical incision for some field sites.

**Model predictions for intrinsic terrace generation can focus field efforts for identifying the imprint of climate change in river valleys.**

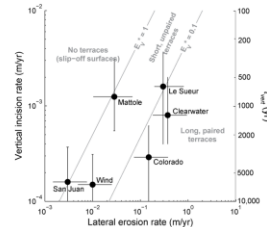
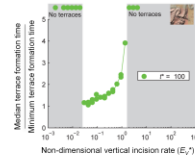
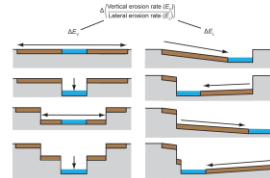


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# Conclusions

- River terrace formation is commonly attributed to pulses of vertical incision driven by climate change.
- Simulations indicate that unsteady lateral erosion can also generate terraces at regular time intervals set by the vertical incision rate.
- Interpretations of climate history from river terraces are more reliable for rivers with relatively high vertical ( $>1$  mm/yr) and low lateral ( $<1$  cm/yr) erosion rates.



Presenter's notes: The timescales for terrace formation by meandering and by climate change may overlap for relatively low vertical incision rates (i.e.,  $\leq 0.1$  mm/yr).