Mechanisms of Drainage Reorganization Driven by Folded Bedrock Geology

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Abstract

Over geologic time, landscapes are shaped by the interactions between fluvial, hillslope, and tectonic processes. Geomorphologists use landscape evolution models (LEMs) to study these interactions. In the most standard approach of LEMs, climate, tectonics, and lithology have limited variability. However, field observations indicate that lithology can have a first order effect on determining landscape form and drainage organization. In this study, we use a LEM (using Landlab's lithology library) to study the effects of heterogeneous lithology on drainage network reorganization by subjecting the landscape to an idealized layer of folded rock with less erodibility, i.e., harder rock. In a series of experiments, we alter the fold geometry and the folded rock erodibility. In our simulations, the crests of the folds promote ridge formation. When the ridges develop on the landscape, they have the ability to either block or redirect flow, but some higher-order rivers have the erosional power to cut through the ridges. For folds that vary in the perpendicular direction to the river, folded bedrock can straighten the river's pathway. For folds that vary in a parallel direction to the river, folded bedrock can block low-order rivers while high-order rivers pass, promoting a trellis drainage pattern. We adjusted erodibility of the folded bedrock and found that higher fold erodibility (relative to the surrounding rock) amplifies these effects. Our results demonstrate the mechanisms that reorganize drainage patterns driven by heterogeneous lithology. In our future work, we plan on further exploring different fold geometries and other types of lithologic structure.

Key Points

1. Folded bedrock's role in LEMs change the drainage networks organization.
2. Hard rock may diverge and be a barrier that change drainage networks.
3. Results suggest the harder the folds, the more pronounced the crests protrude and reorganize drainage networks' landscape.

Background

- Fluvial erosion through heterogeneous lithologic properties can be a first order determinant on drainage network organization[1]
- Previous numerical modeling[2] has studied simple stratigraphy (i.e., layer-cake), where drainage reorganization was limited[3]
- In this study, we use a landscape evolution model (LEM) to simulate an idealized folded bedrock to study the effects of lithologic heterogeneity and structure on drainage network reorganization

Methods

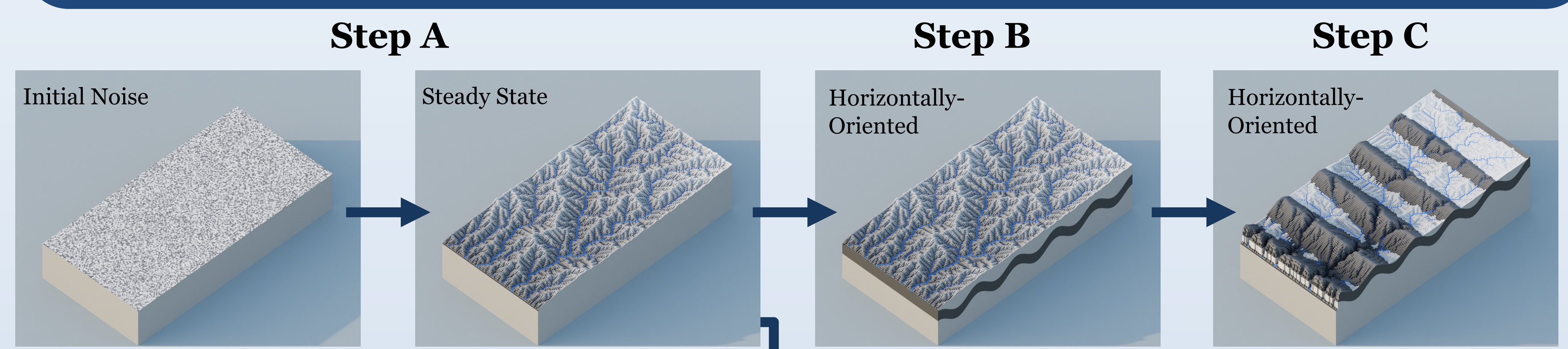
- We utilized Landlab[4] and the Lithology[5] module to develop the LEM and to create an idealized folded bedrock stratigraphy.

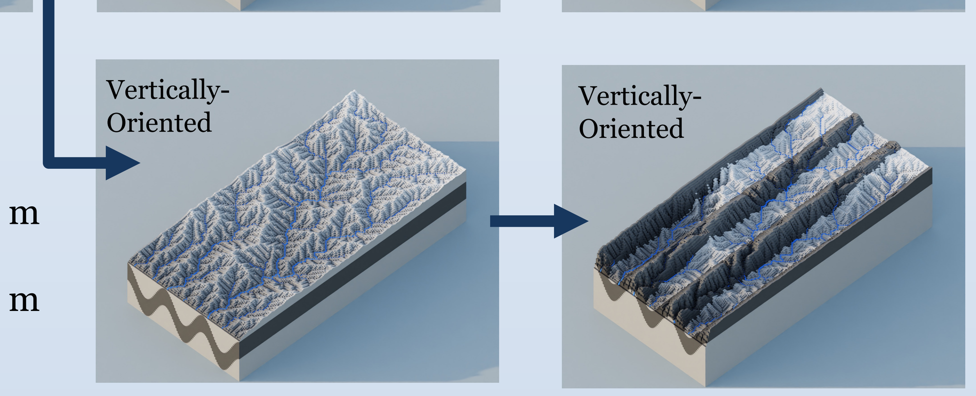
$$\frac{\partial \eta}{\partial t} = U - KA^m S^n + D\nabla^2 \eta$$

η-elevation, *t*-time, *U*-uplift rate, *K*-erodibility rate, *A*-drainage area, S-slope coefficient, *m* and *n* are positive exponents, *D*-diffusion coefficient

Parameter	Definition	Value	Unit
U	Uplift Rate	0.001	m/yr
K_o	Base Erodibility	0.0001	1/yr
K_f	Fold Erodibility	varies	1/yr
D	Hillslope Diffusion Coefficient	0.01	m²/yr

Model Setup





- **Step A** – Initial Topography -> Steady State
  - 3 closed and 1 open boundary
- **Step B** – Introduce Sinusoidal Fold
  - Horizontally Oriented – 100 m thickness, 50 m amplitude, 2 km wavelength
  - Vertically Oriented - 150 m thickness, 100 m amplitude, 1.67 km wavelength
- **Step C** – Observe Drainage Network Change

Numerical Results

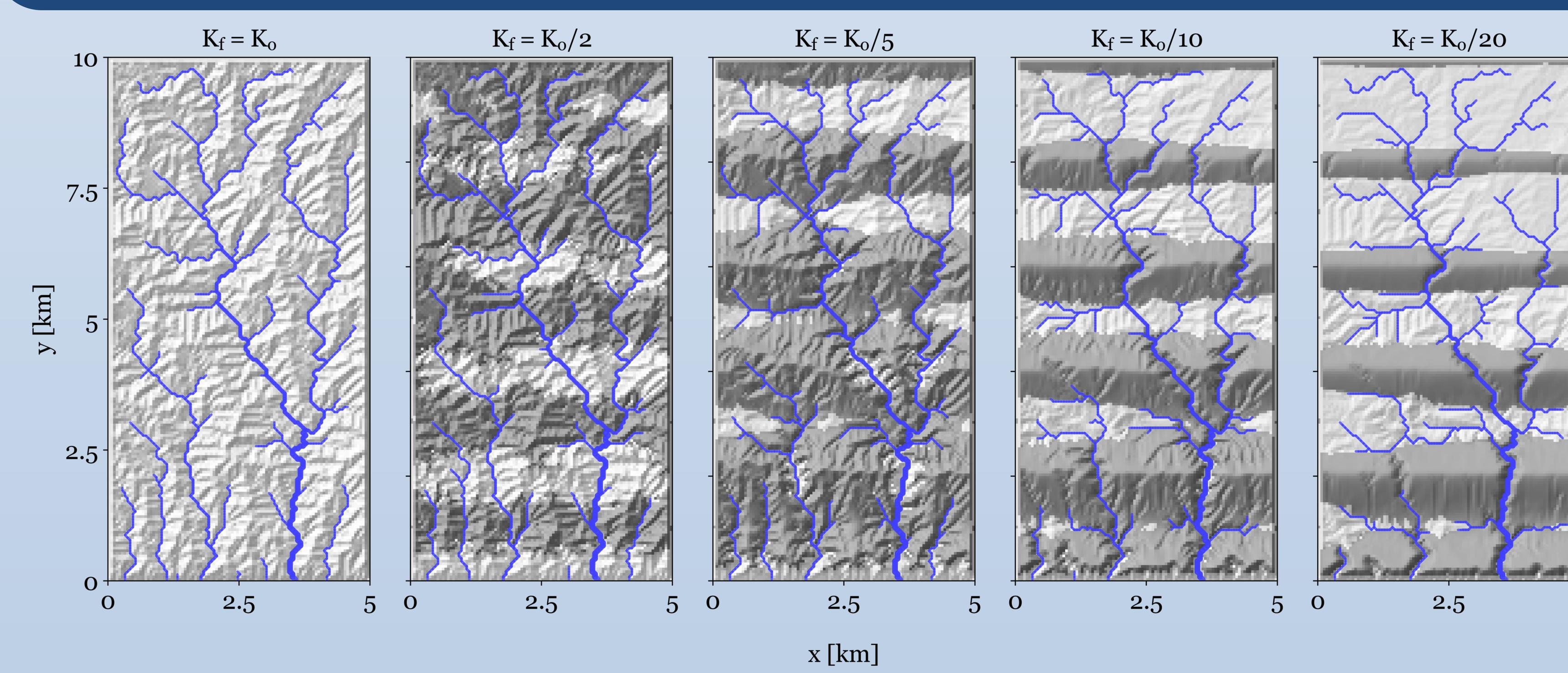


Figure 1: Landscapes and river network eroding into horizontally oriented folds from 5 simulations where fold erodibility (K_f) varies with respect to the surrounding rock, *K*. Gray and white parts of the landscape represented harder and softer rock, respectively. This shows a timeframe of 200K years after the fold is introduced.

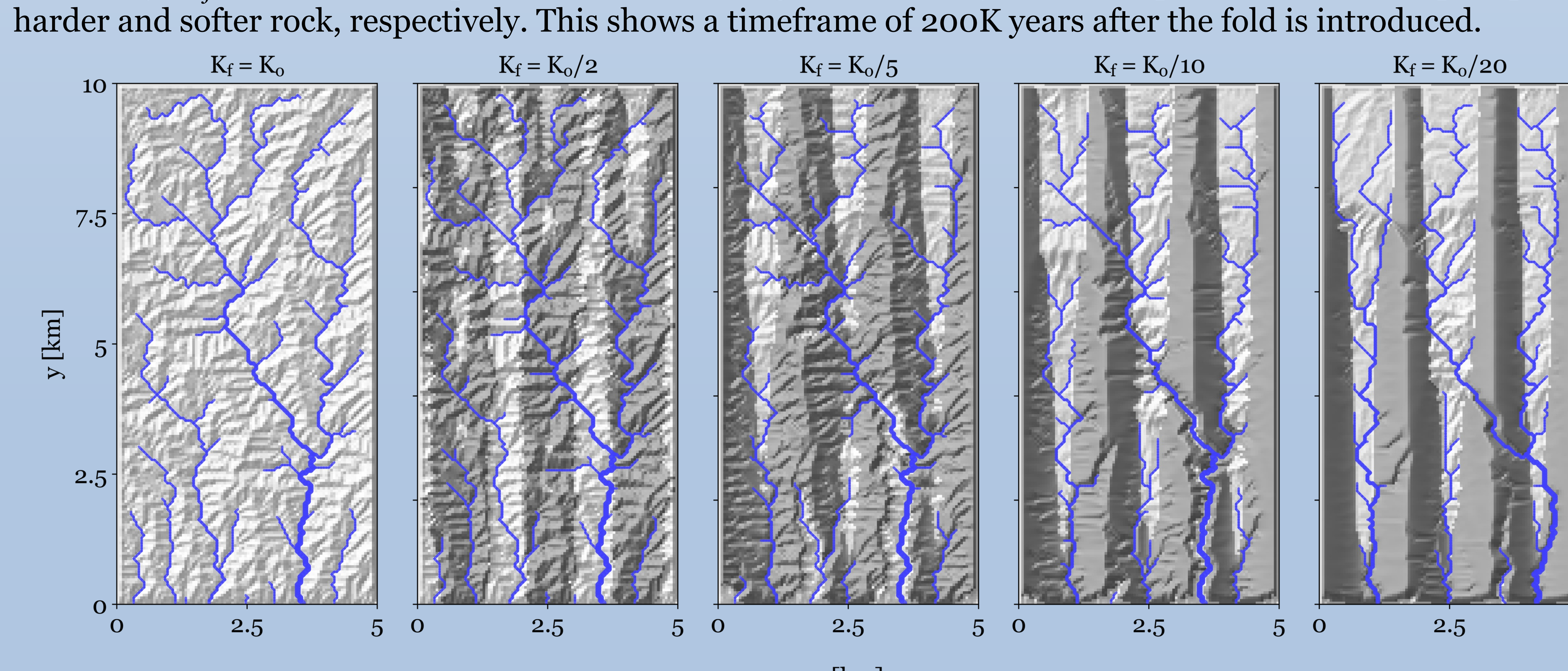


Figure 2: Landscapes and river network eroding into vertically oriented folds from 5 simulations where fold erodibility (K_f) varies with respect to the surrounding rock, *K*. Gray and white parts of the landscape represented harder and softer rock, respectively. This shows a timeframe of 270K years after the fold is introduced.

Numerical Results Continued

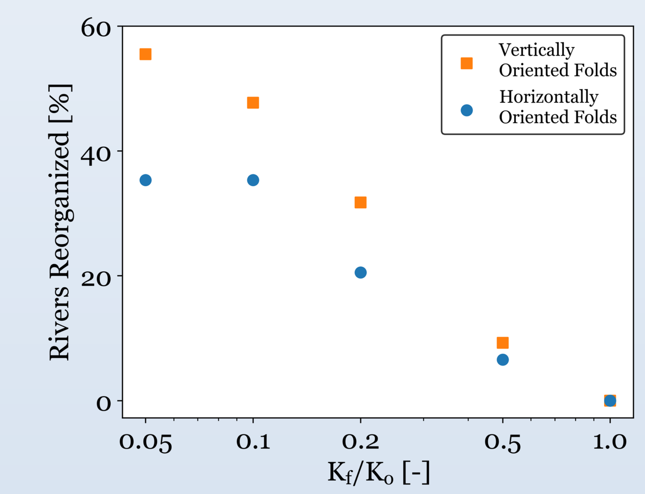


Figure 3: Plot relating K_f/K_o ratio and river reorganization. As the bedrock folds become harder than its surrounding rock, more river reorganization occurs.

- When K_f/K_o is low, horizontally oriented folds promote trellis drainage patterns, and vertically oriented folds foster parallel drainage formation.
- As the ratio of K_f/K_o decreases, river reorganization increases.
- When the contrast between K_f/K_o is 1/10, the ~40-60% of the rivers are reorganized.

Discussion and Future Work

1. The crests of the harder rock protruded in the landscape, blocking and redirecting flow, reorganizing the drainage network.
2. Model simulations show that weaker streams cannot penetrate folded bedrock crests, while stronger streams could.
3. Therefore, rock heterogeneity and other types of complex structure (i.e., non-layer cake) may drive significant drainage reorganization.
4. Further exploration of different fold geometries and other types of lithology may demonstrate alternate patterns of drainage networks.

Acknowledgements

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