Drainage network reorganization in landscapes buried by glacial deposits

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Background and Motivation

- The study of drainage network emergence and reorganization reveal the complex interplay between geomorphic and tectonic processes.
- Geomorphologists use **Landscape Evolution Models (LEMs)** to simulate drainage network dynamics.
- Standard LEM approaches center on limited variability in climate and lithology or simple stratigraphy.
- However, there is a growing consensus that **lithologic variability can have a first-order control on drainage network organization**.

Upper Mississippi River Basin

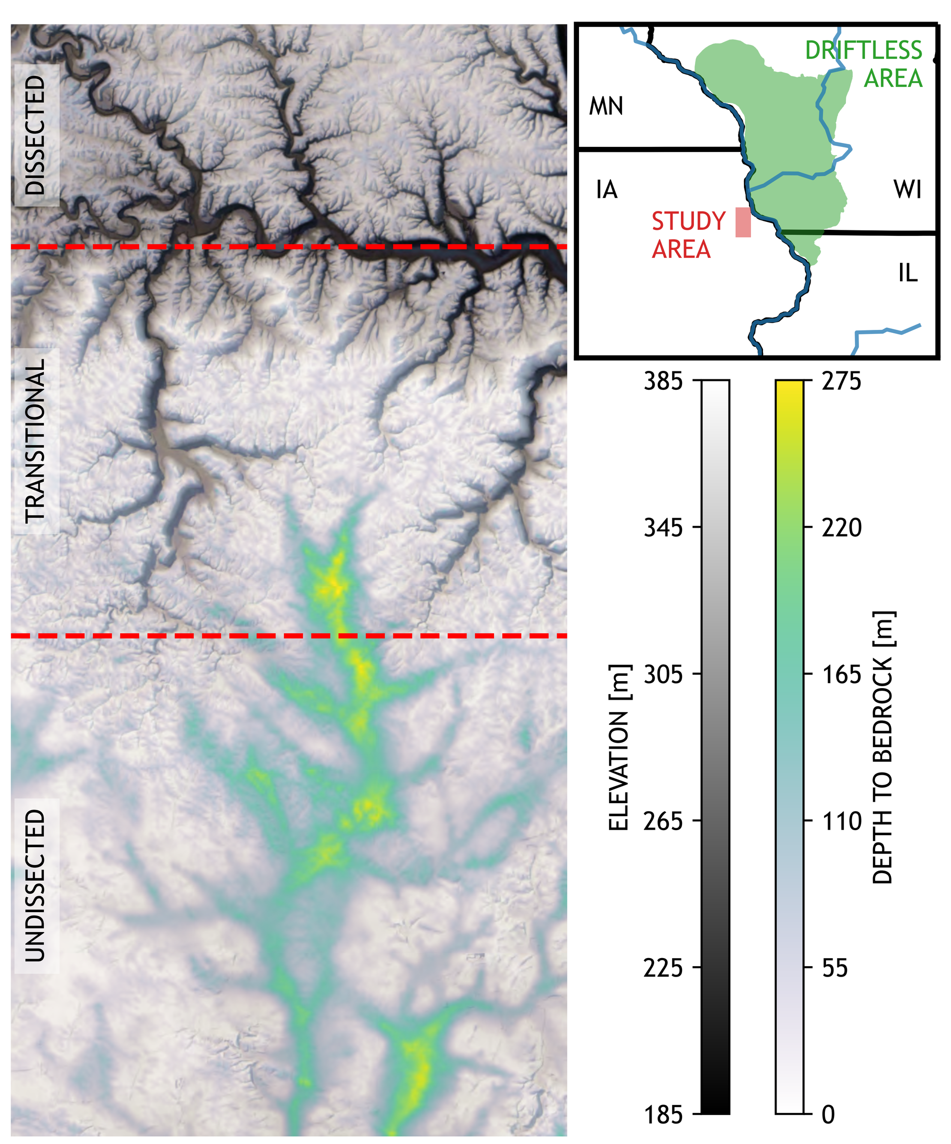

Figure 1. Hillshade map overlaid with a depth to bedrock map located in Eastern Iowa. Dissected regions are characterized by fully developed drainage networks into Paleozoic sedimentary bedrock. In the transitional region, river knickpoints erode into an upland plateau covered in glacial till (undissected region).

Our study and numerical models are inspired by regions like the **Upper Mississippi River Basin**.

- **Before Pleistocene glaciation**, the mature drainage networks developed into Paleozoic sedimentary rock.
- **During Pleistocene glaciation**, glacially transported till buried the old landscape.
- **After Pleistocene glaciation**, new drainage networks were established on the till-covered surface.

Newly established drainage networks on the surface do not necessarily coincide with the paleodrainage networks shown in the depth to bedrock data (**Fig. 1**).

Research Objectives

As the glacial till erodes and the bedrock reemerges, the drainage network must make a choice between

- maintaining the **modern drainage network**
- reorganizing into the **paleodrainage network**

Using an **LEM**, we aim to:

1. determine the governing parameters that control this decision
2. identify geopatterns that signify drainage reorganization

Numerical Landscape Evolution Model

Conservation Equation:

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

- η - elevation [m]
- t - time [yr]
- K - erodibility of bedrock (K_B) and till (K_T) [m^{1-2m} yr^{-1}]
- A - drainage area [m^2]
- S - channel slope [-]
- D - hillslope diffusion coefficient [m^{2}yr^{-1}]
- m, n - area and slope exponents [-]

Baselevel Fall:

$$\frac{\partial \eta_{Outlet}}{\partial t} = -B$$

- B - baselevel fall rate [mm yr^{-1}]

Model Setup

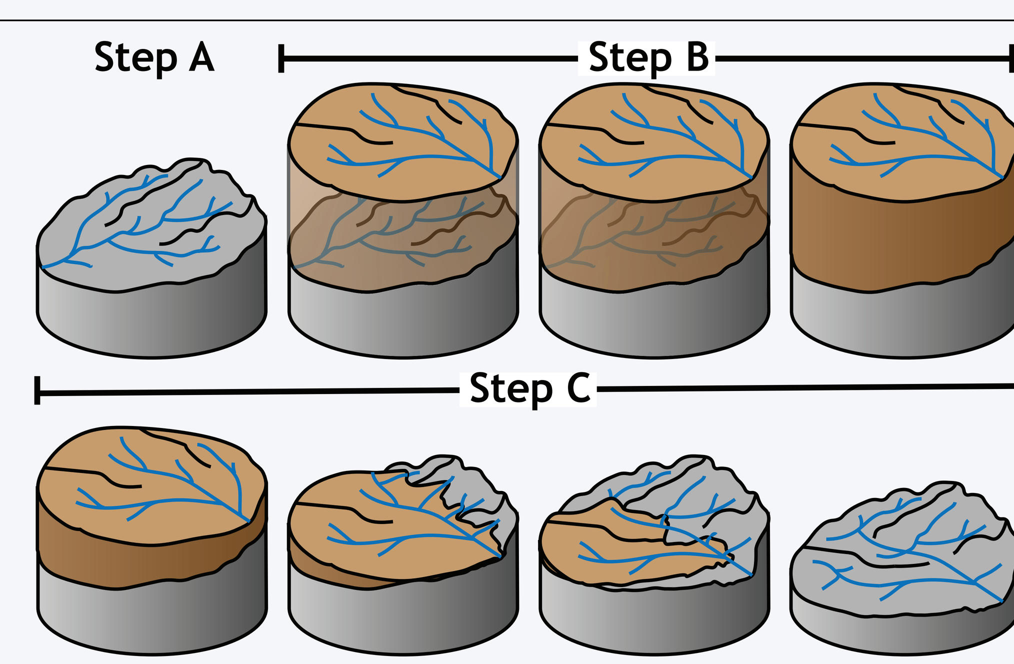

Figure 2. Model setup schematic.

- Our model utilizes a circular domain to minimize the influence of the boundary.
- The landscape drains out of a single outlet point that lowers, and the remaining boundaries are closed.
  - **Step A** - Evolve bedrock landscape to dynamic equilibrium
  - **Step B** - Bury landscapes entirely and establish a new outlet
  - **Step C** - Evolve landscape until all glacial till is eroded, and a new equilibrium is achieved

Buried Landscape Parameters

1. K_T/K_B - erodibility contrast between glacial till and bedrock
2. θ_{outlet} - the deviation angle between the paleodrainage outlet and modern drainage outlet

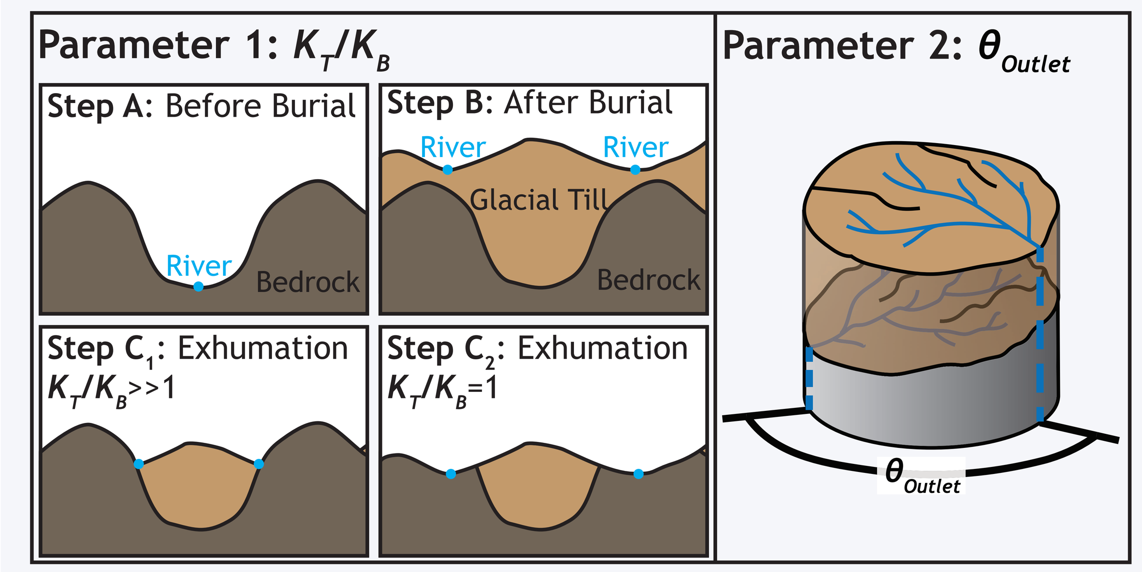

Figure 3. Schematic of buried landscape parameters.

Example Simulations

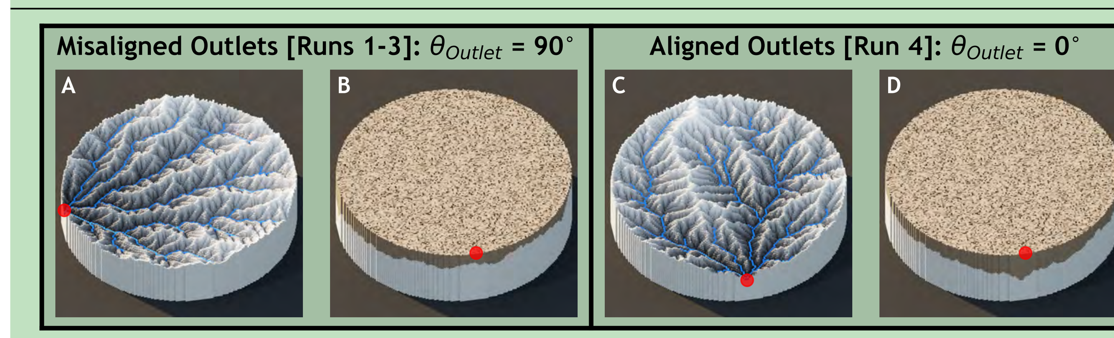

Figure 4. (**A**, **C**) Bedrock landscapes at dynamic equilibrium. (**B**, **D**) Landscape buried with glacial till. (**A**-**B**) Paleo- and modern outlets are misaligned ($\theta_{outlet} = 90°$). (**C**-**D**) Outlets are aligned ($\theta_{outlet} = 0°$). Red circles denote outlet locations. K_B = 1 x 10^{-5} yr^{-1}; D = 2 x 10^{-3} m^2 yr^{-1}; B = 1 mm yr^{-1}; Area = 78.5 km^2.

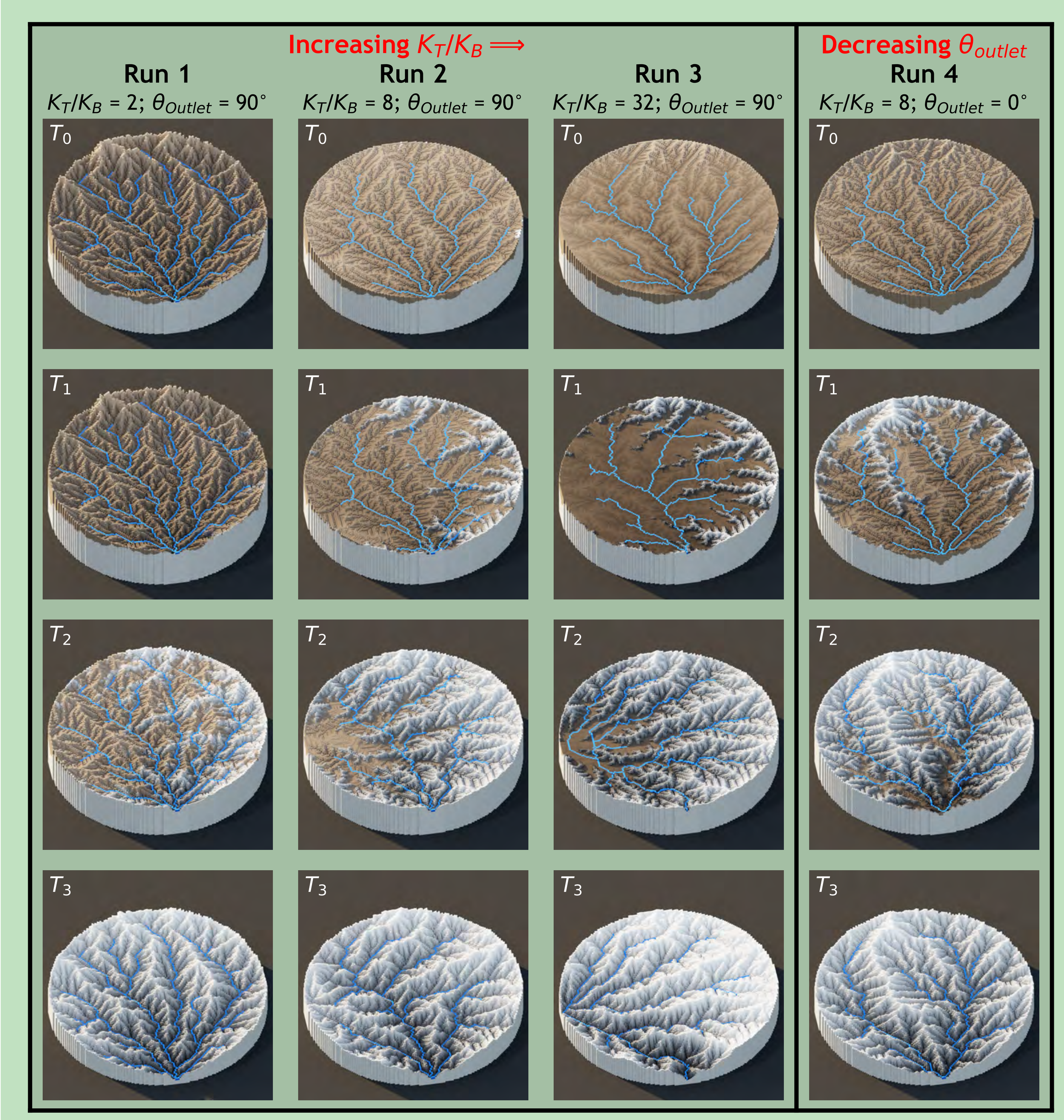

Figure 5. Four simulations varying K_T/K_B [**Runs 1-3**] and θ_{outlet} [**Runs 2 vs. 4**]. (***T*$_0$**) Modern drainage network establishes on glacial till surface (light brown). (***T*$_{1-2}$**) Glacial till is gradually eroded away, exposing the bedrock surface (gray). (***T*$_3$**) Bedrock is fully exposed and reaches a new dynamic equilibrium.

Drainage Network Metrics

1. **Local Aspect Deviation** - angle difference in local surface slope direction
2. **Drainage Tortuosity** - stream path length divided by shortest path length

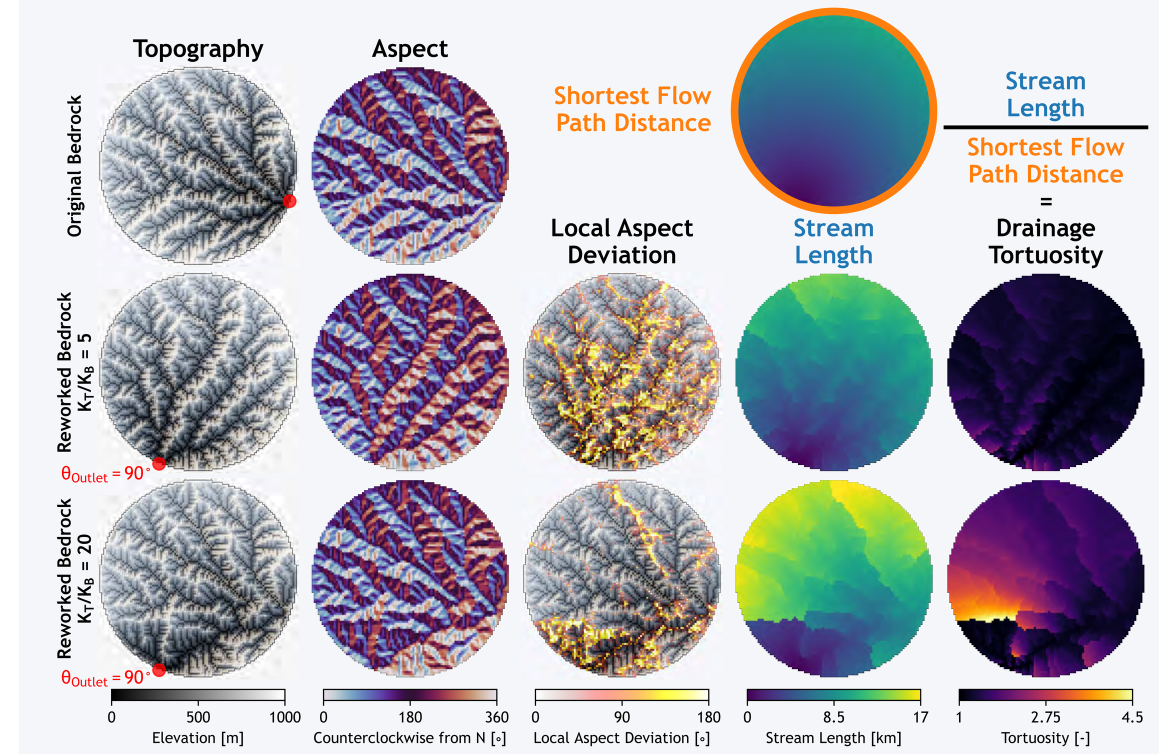

Figure 6. Schematic of drainage network metrics.

Sensitivity Analysis

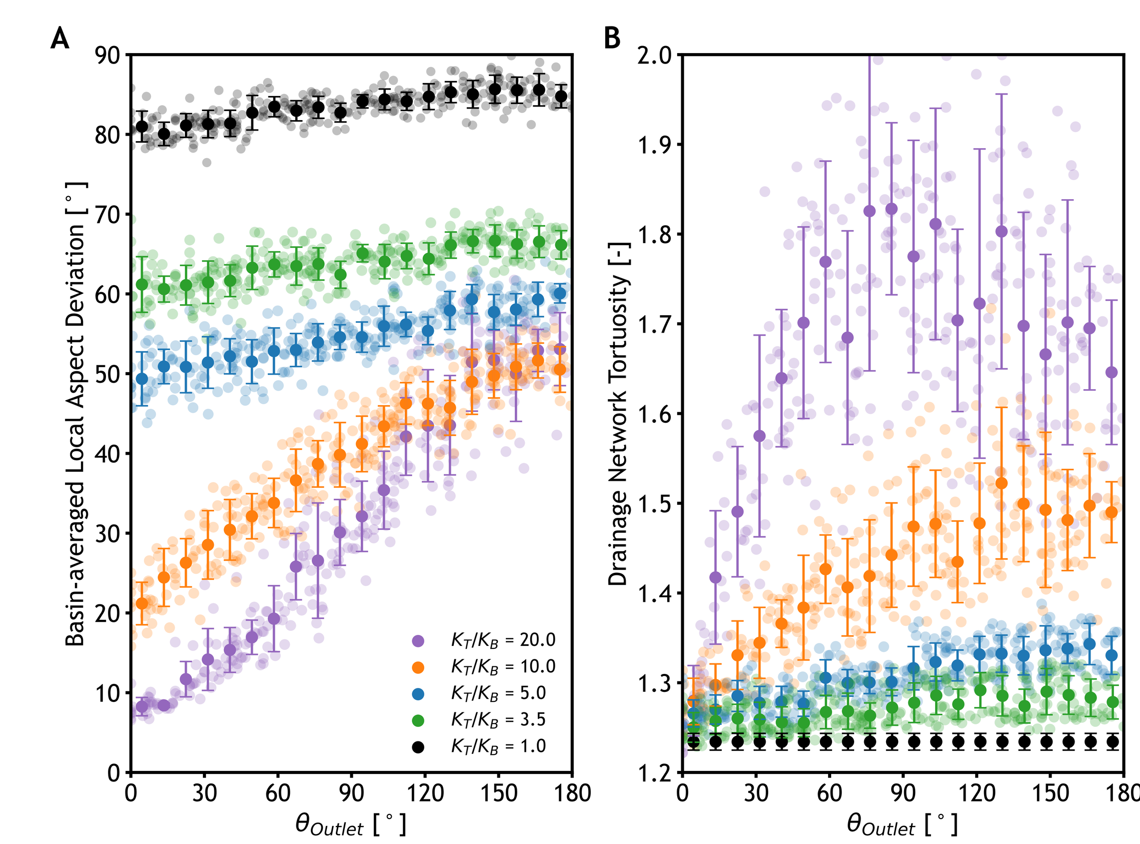

Figure 7. Basin-averaged local aspect deviation (**A**) and Drainage Network Tortuosity (**B**). Translucent circles represent individual simulations, opaque circles signify binned values, and whiskers show a one standard deviation range.

Discussion & Conclusions

1. Basin-averaged Deviation in Local Aspect (**BLAD**) quantifies the landscape's memory of the paleodrainage network and original bedrock morphology.
   - BLAD decreases (more memory) with K_T/K_B.
   - Bedrock memory becomes apparent when $K_T/K_B > 5$.
   - BLAD increases (less memory) with θ_{outlet}.
2. Drainage Network Tortuosity (**DNT**) quantifies the degree of drainage reorganization.
   - Higher DNT indicates the prevalence of barbed tributaries and drainage reversals.
   - Next step is to test if DNT can located landscapes that were shaped by lithologic variability.