Chaotic chasms: Canyon evolution governed by autogenic channel-hillslope feedbacks

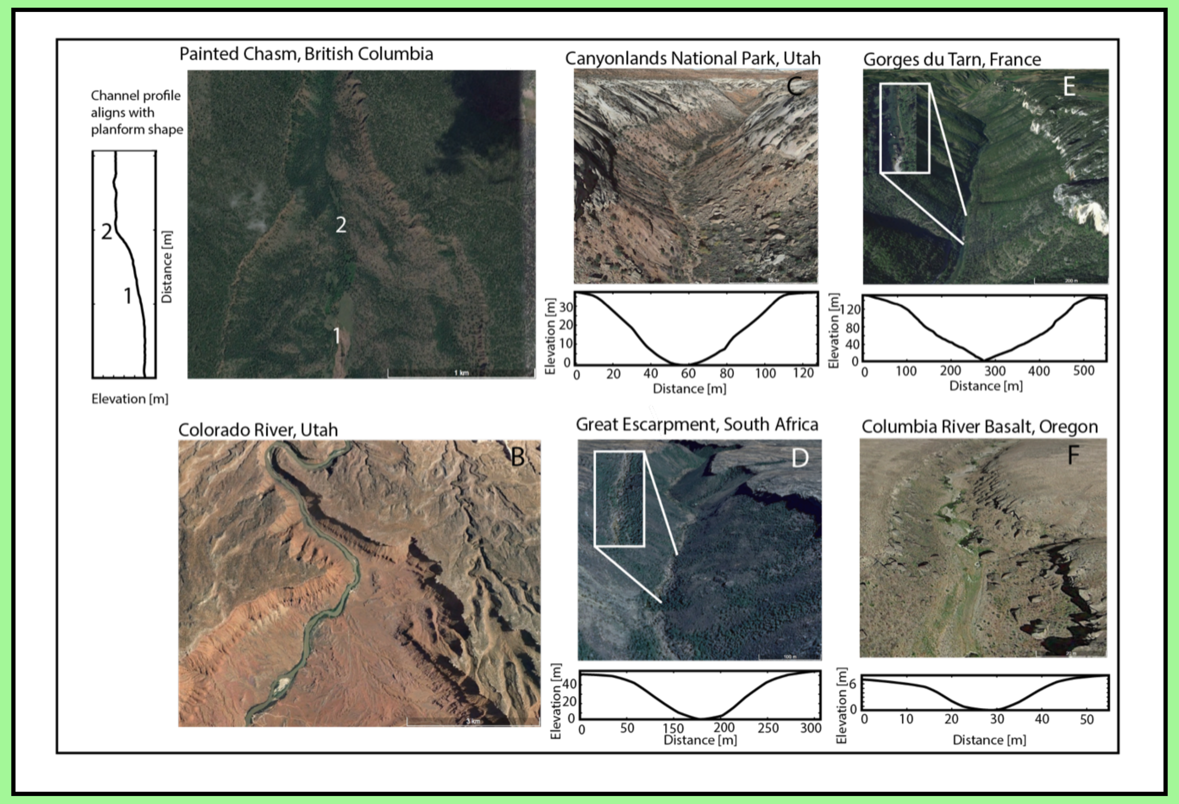
Charles M. Shobe[1,3,*] (charles.shobe@colorado.edu), Rachel C. Glade[2,3,*], Robert S. Anderson[2,3], and Gregory E. Tucker[1,3]

[1]CIRES, [2]INSTAAR, and [3]Department of Geological Sciences, University of Colorado. *Equal contributors

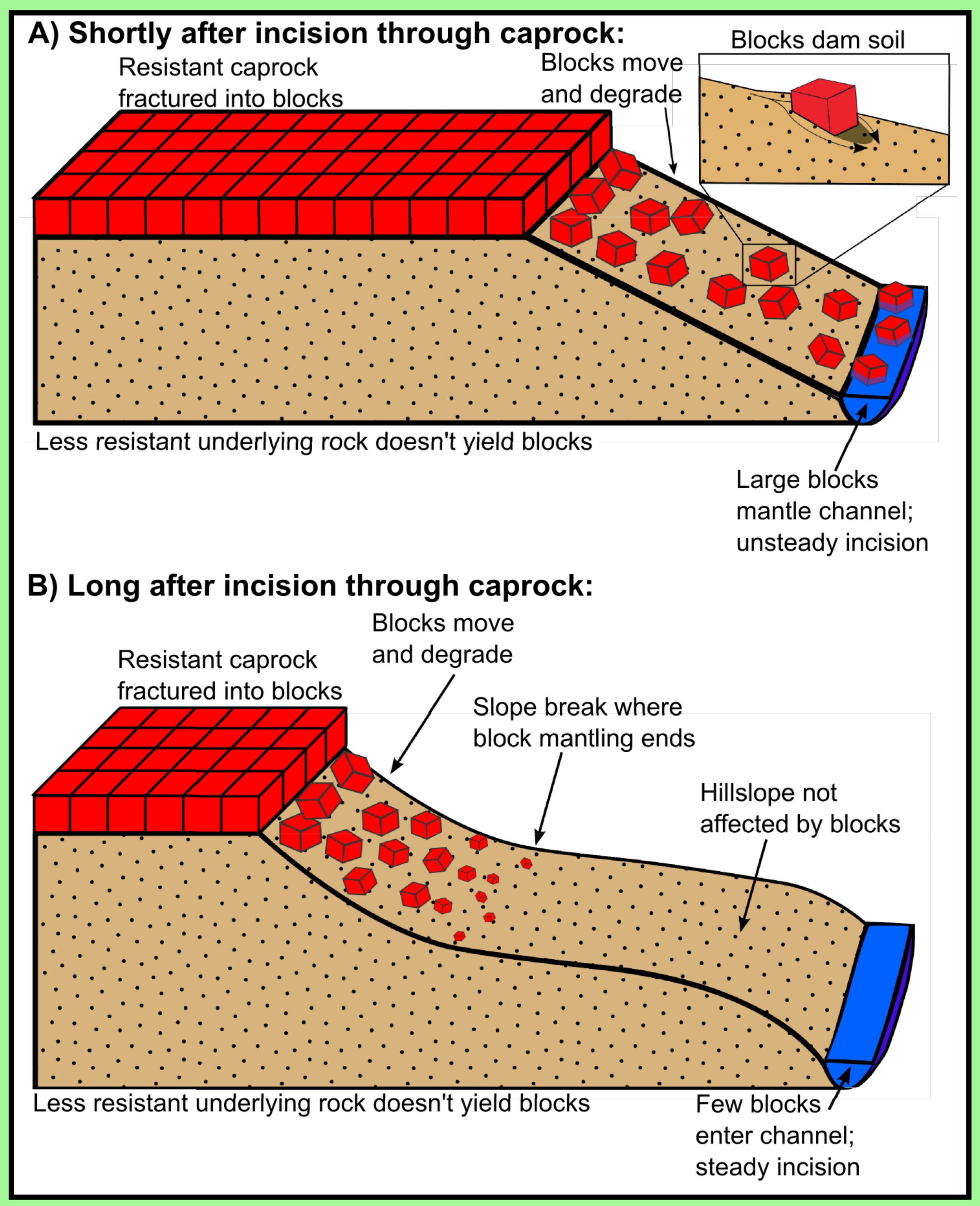
Highlights

- We develop a conceptual model of canyon erosion in which two-way feedbacks between channels and rocky hillslopes set erosion rates and canyon shape.
- Numerical modeling shows that internal feedbacks cause persistent erosion rate unsteadiness that can overwhelm external signals and set landscape form.

Field observations of river canyon form



Conceptual model of river canyon development



Numerical modeling approach and assumptions

Our numerical model results from coupling previously published models for the evolution of rocky hillslopes (Glade et al., 2017; Glade and Anderson, 2018) and block-influenced bedrock river channels (Shobe et al., 2016; 2018).

Hillslope evolution

- Depth-dependent soil production and transport.
- Blocks inhibit soil production and flux.
- Blocks move downslope based on a relief threshold and weather at a constant rate.

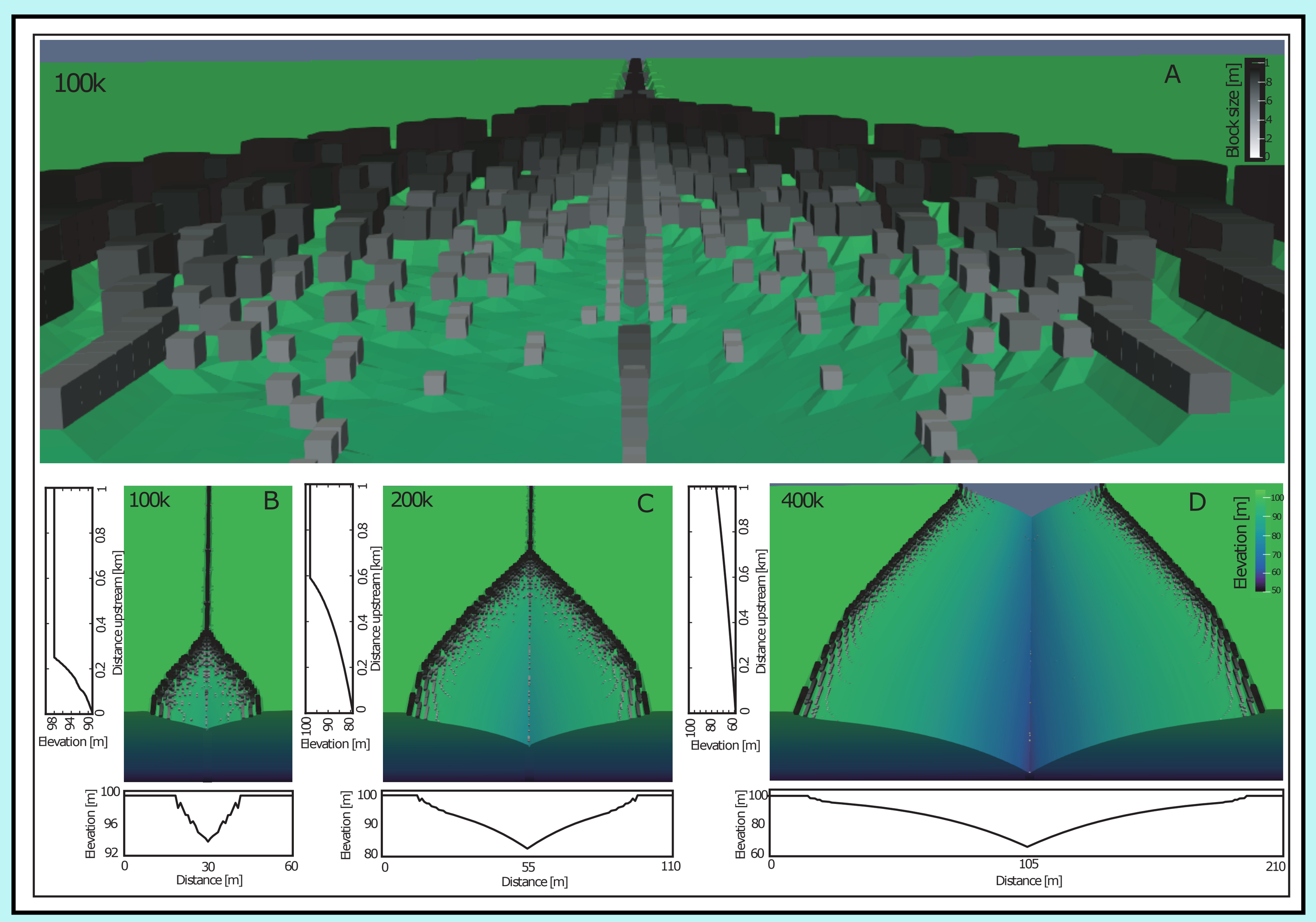
Channel evolution

- Shear stress erosion rule.
- Blocks inhibit erosion by covering the channel bed; extracting flow energy.
- Blocks move according to a sliding force balance and weather in proportion to fluid stresses acting on them.

Key model assumptions:

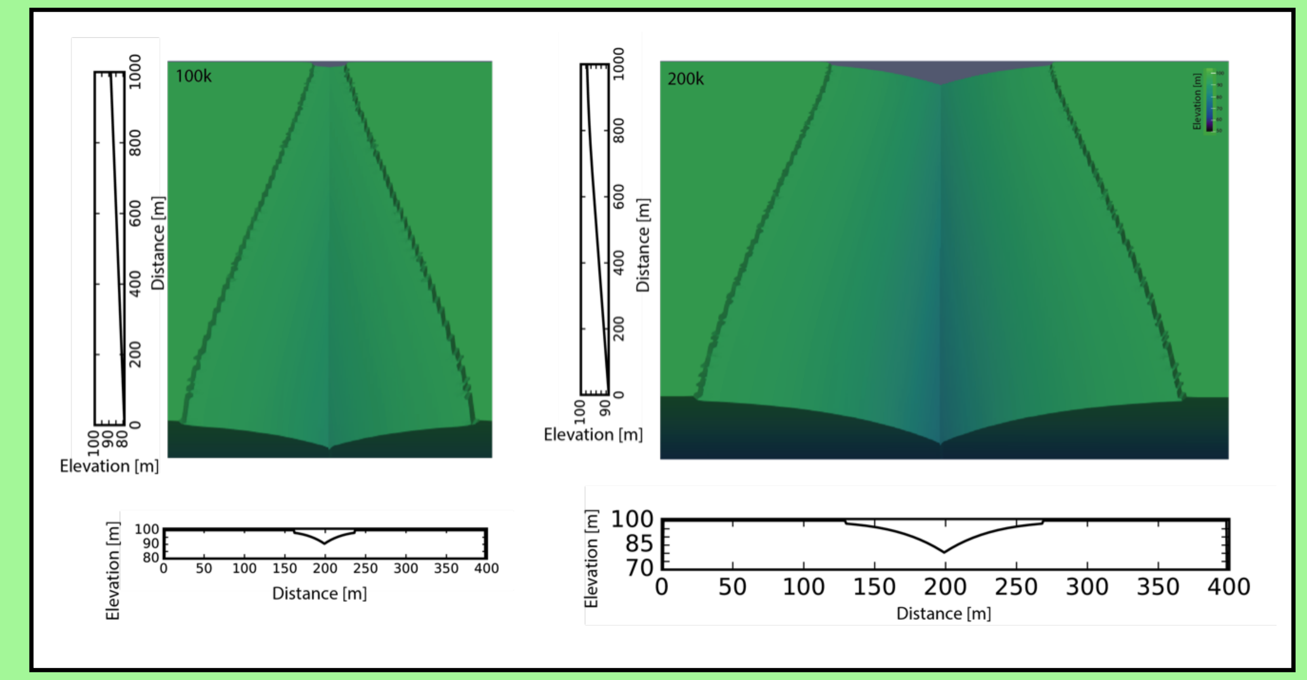
- The domain is a channel reach of constant drainage area.
- Overland flow effects on hillslope morphology are negligible.
- Hillslope failures (e.g., landslides) do not occur even at steep slopes.
- Blocks released from the resistant layer have a constant initial size.
- Blocks, when released, land adjacent to the resistant layer.

Numerical modeling results

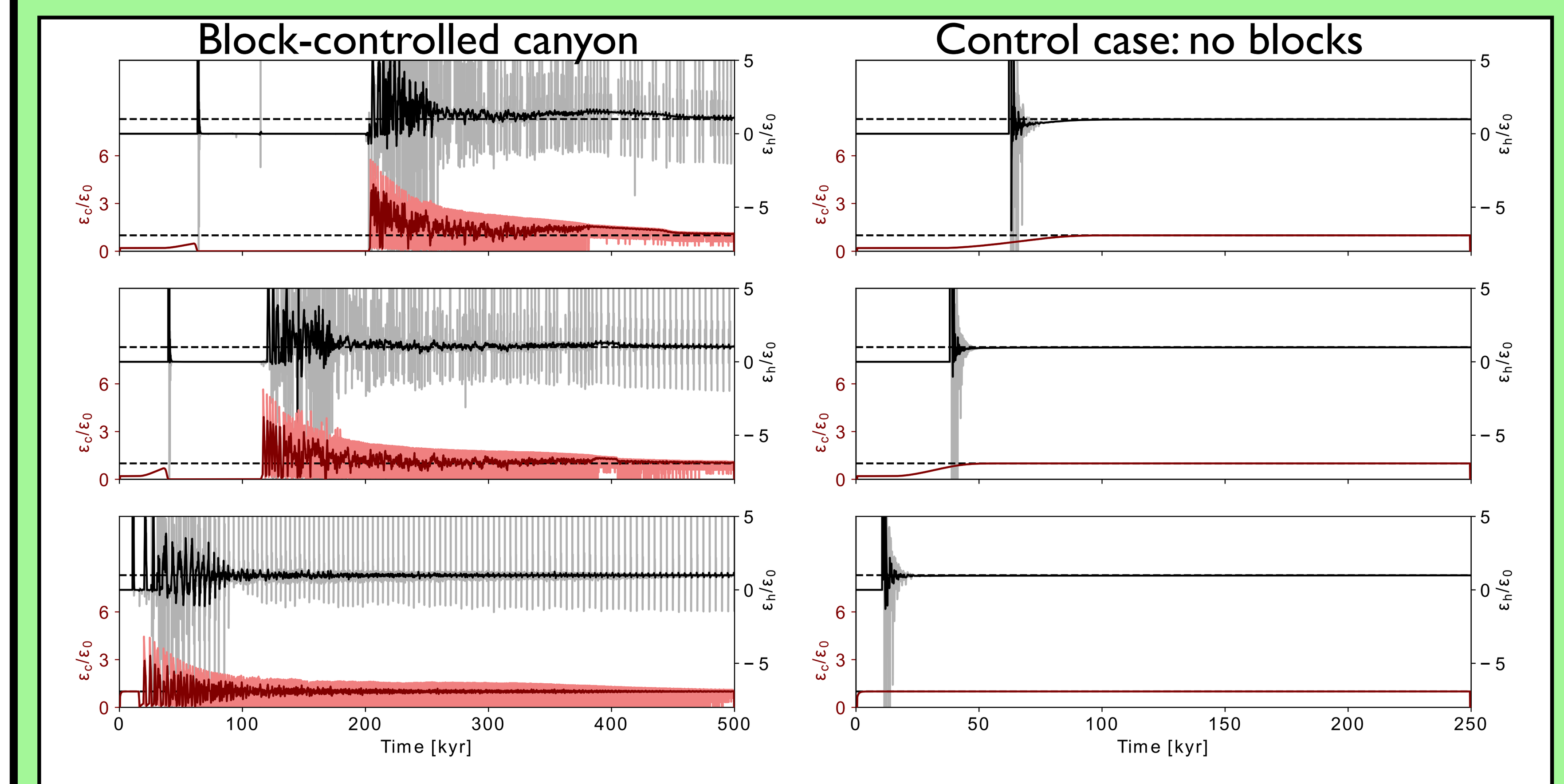


- The model was forced with a constant baselevel lowering rate at the downstream end of the channel reach.
- Planview canyon shape is governed by the upstream propagation of the baselevel signal, which in turn is strongly modulated by block delivery.
- Hillslope profiles match conceptual model predictions: hillslopes are linear-to-concave near the caprock and convex as the block influence wanes.

Results of no-blocks control experiment



Erosion rates in block-controlled canyons



Conclusions

- Internal, two-way channel-hillslope feedbacks result in diagnostic canyon shapes both in planview and cross-section.
- Hillslope block delivery, responding to channel incision, causes oscillations in channel erosion rates that persist over landscape evolution timescales.
- Caprock canyons are tightly coupled channel-hillslope systems.

References and acknowledgements:

Glade, R.C., Anderson, R.S., and Tucker, G.E. (2017) Block-controlled hillslope form and persistence of topography in rocky landscapes, Geology.

Glade, R.C. and Anderson, R.S. (2018) Quasi-steady evolution of hillslopes in layered landscapes: An analytic approach. JGR-ES.

Shobe, C.M., Tucker, G.E., and Anderson, R.S. (2016) Hillslope-derived blocks retard river incision. GRL.

Shobe, C.M., Tucker, G.E., and Rossi, M.W. (2018) Variable-threshold behavior in rivers arising from hillslope-derived blocks. JGR-ES.

This work was supported by NSF EAR-1323137, EAR-1331828, EAR-1552883, ACI-1147454, and ACI-1450409. CMS was supported by a National Defense Science and Engineering Graduate Fellowship and a University of Colorado Chancellor's Fellowship.