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Modeling and Observations of Outlet Canyons from Lake Overflow Floods on Early Mars

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I. Introduction

Numerous observations from both orbital remote sensing [1-3] and Mars Curiosity [4] suggest that lakes were once part of the martian landscape. From orbital data, one of the key lines of evidence for past paleolakes is the existence of several hundred valley network-fed basins – usually craters – that have outlet valleys that remain perched above their floors [e.g. 2]. The existence of outlets requires that water ponded to the point that it overflowed confining topography.

Beyond recognizing these landforms, there has been only limited work reconstructing the morphometry, formative hydrology, and incision history for these outlets [5]. Here, we describe our recently published observations of outlets [6] and ongoing numerical modeling looking at these factors.

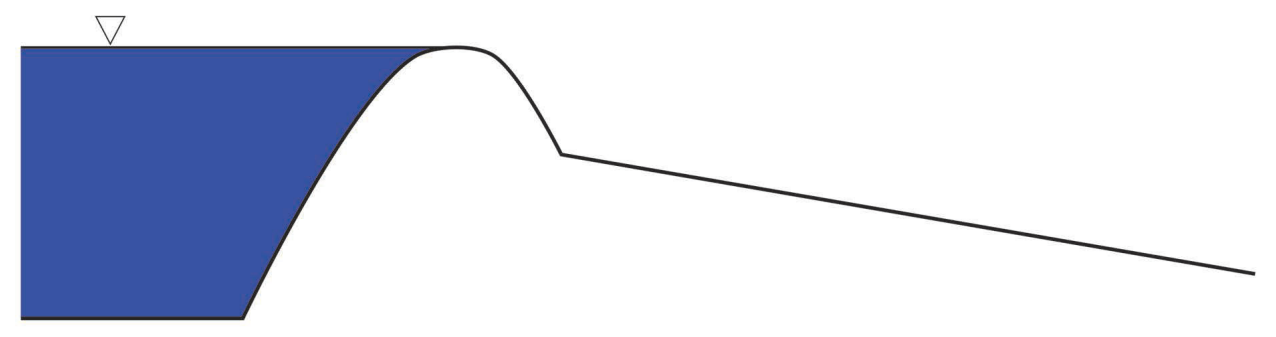
II. Key Takeaways

- The volume of water drained during outlet formation is a significant predictor of outlet breach depth and cross-sectional area, as well as the volume of material excavated from the outlet canyon.
- Scaling relationships between drained volume (and released potential energy) and outlet canyon morphometry are similar on Mars and Earth.
- This is consistent with studied outlet canyons being mostly carved during highly erosive single episodes of lake overflow flooding. This may be a much more important process for landform evolution on Mars than Earth.
- Numerical experiments are helping provide intuition and insight into the hydrodynamics and morphodynamics of this process.

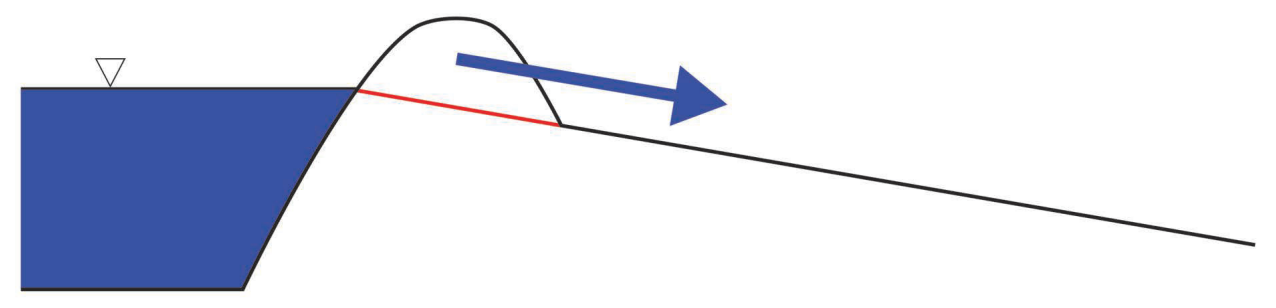
Hot off the presses! Goudge, T.A., Fassett, C.I., and Mohrig, D. (2018), Incision of paleolake outlet canyons on Mars from overflow flooding, *Geology.* https://doi.org/10.1130/G45397.1.

III. Motivation and Observational Strategy

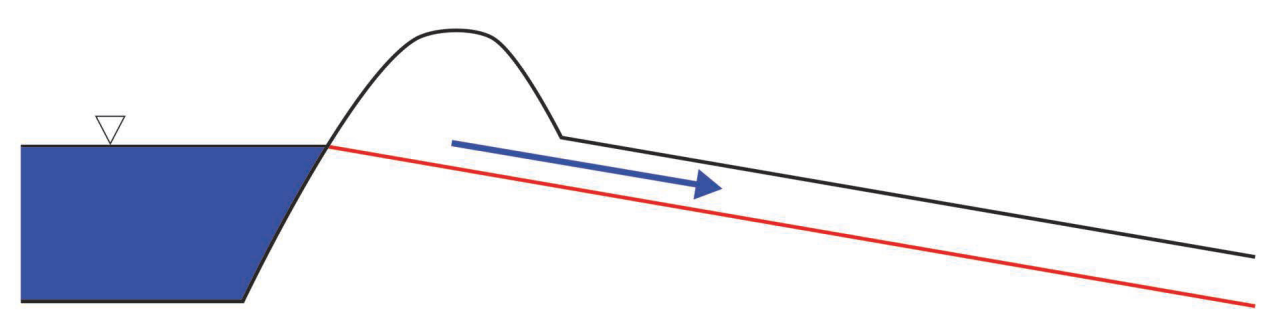
1 Basin fills with water to breaching.



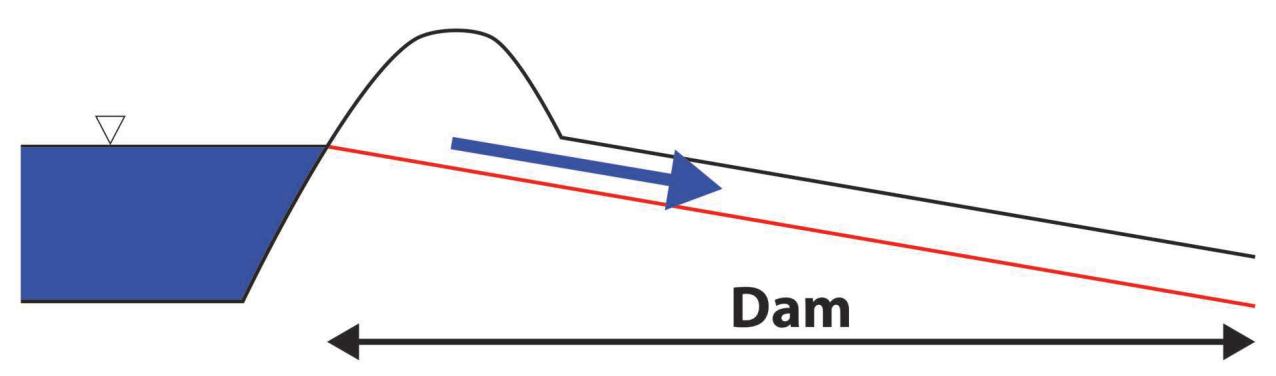
2 Rim is incised to approximately level of background terrain via catastrophic flooding.



3a Hypothesis 1: Normal outflow, recharged by discharge from inlet, continues to incise outlet as basin drains slowly.



3b Hypothesis 2: 'Catastrophic' draining continues, as entire length of outlet canyon now acts as dam.



Two endmember possibilities for outlet formation:

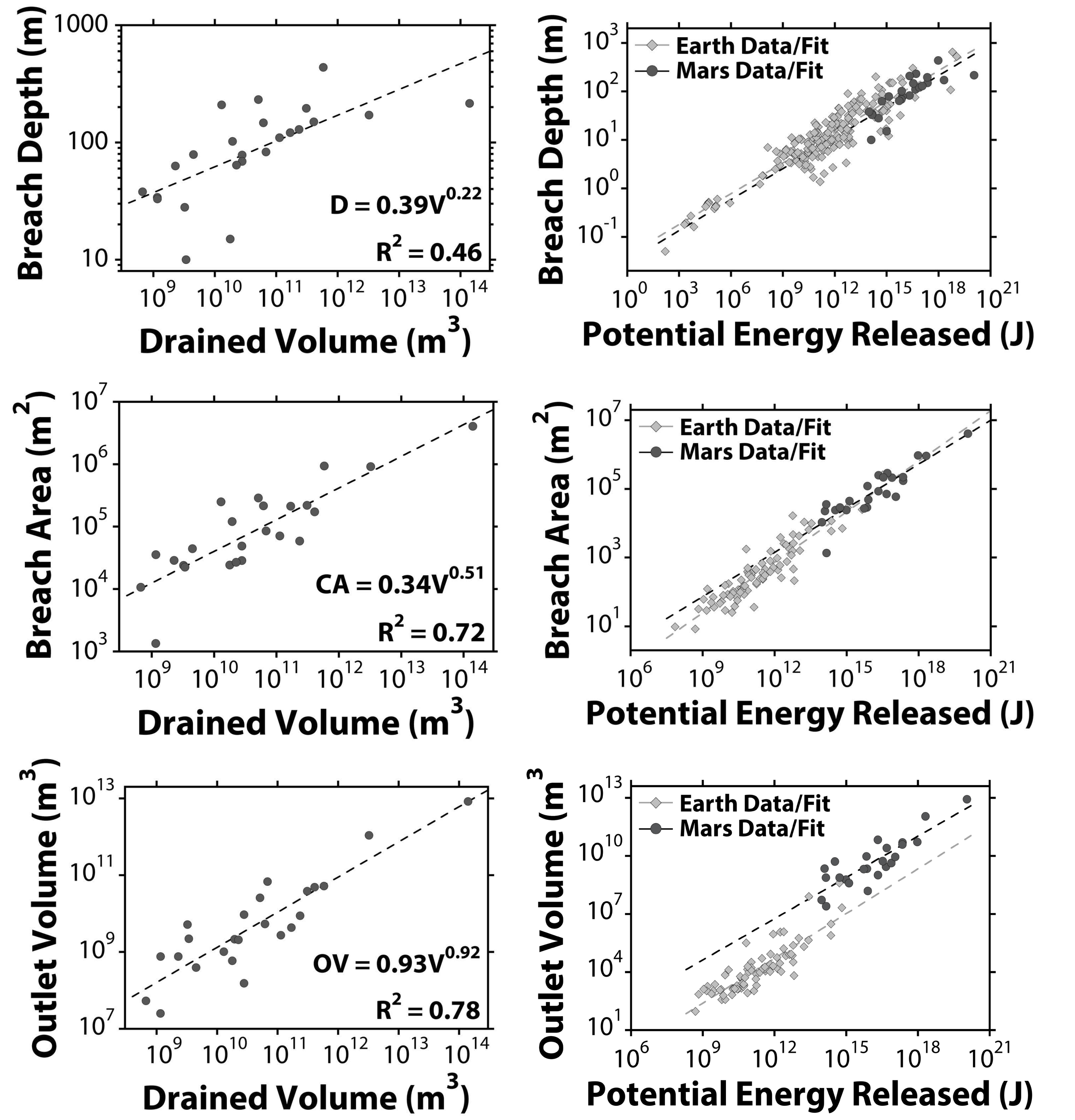
Hypothesis 1: Following breaching, most of the outlet is carved over a geologically long period by standard fluvial processes. Prediction would be that outlet morphometry is not controlled by the basin-breaching flood.

Hypothesis 2: Basin-breaching flood carves most of the outlet canyon in a geologically short period of time. Prediction would be that outlet is controlled by the flood.

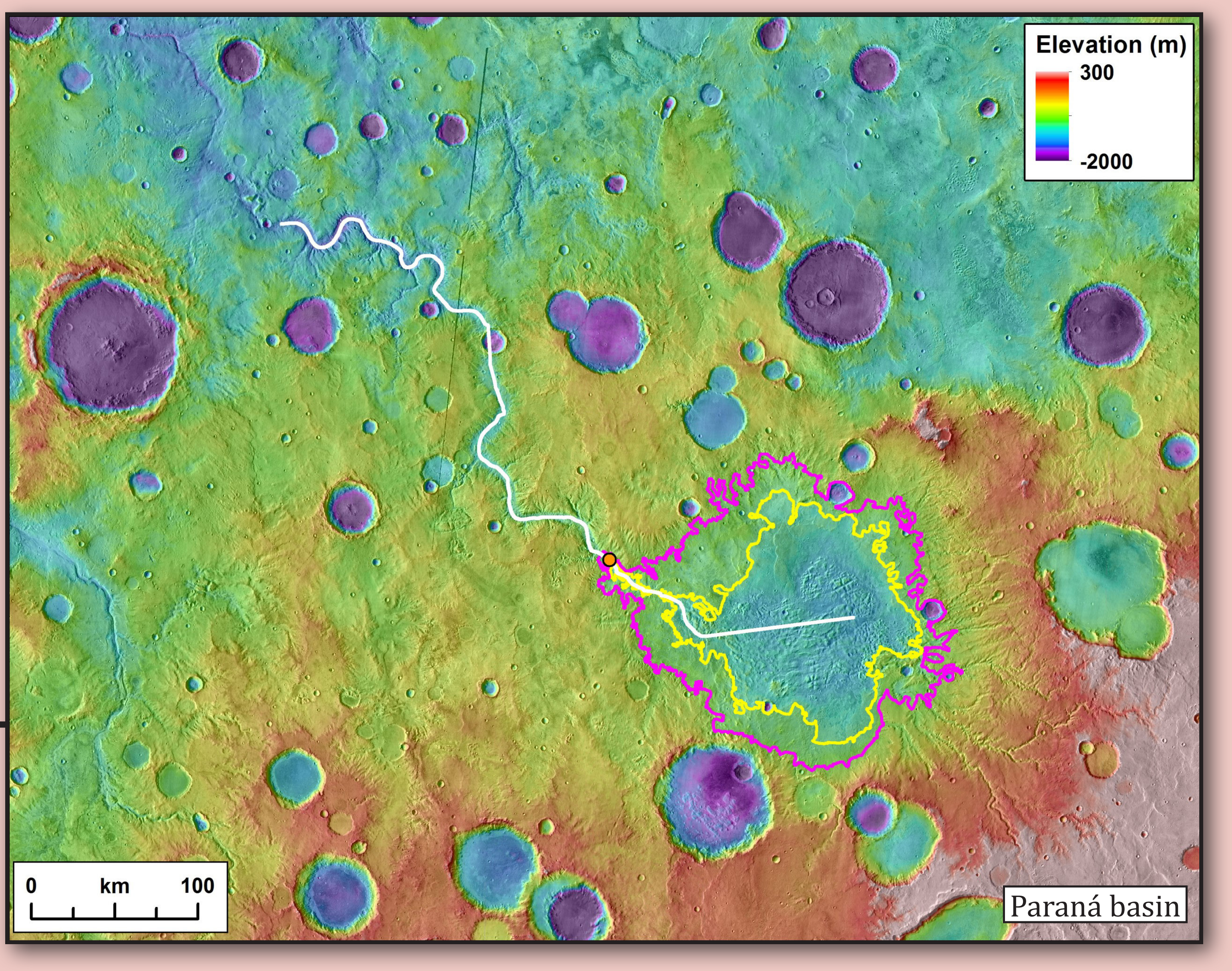
Observational strategy:

- Measured 24 open basin lakes, selected based on availability of stereo DTMs.
- Determined pre-breach highest closed contour (magenta) and post-breach surface elevation (yellow) from current spillover point.
- Measured breach parameters using cross-sectional profile across outlet point, and outlet canyon volume by interpolating measured cross-sectional profiles taken along canyon length.

IV. Observations



Strong correlations exist between lake morphometry and outlet morphometry. In other words, the volume of water drained during outlet incision is a strong predictor of the outlet canyon and breach parameters. This is consistent with outlet canyon incision primarily driven by overflow flooding.

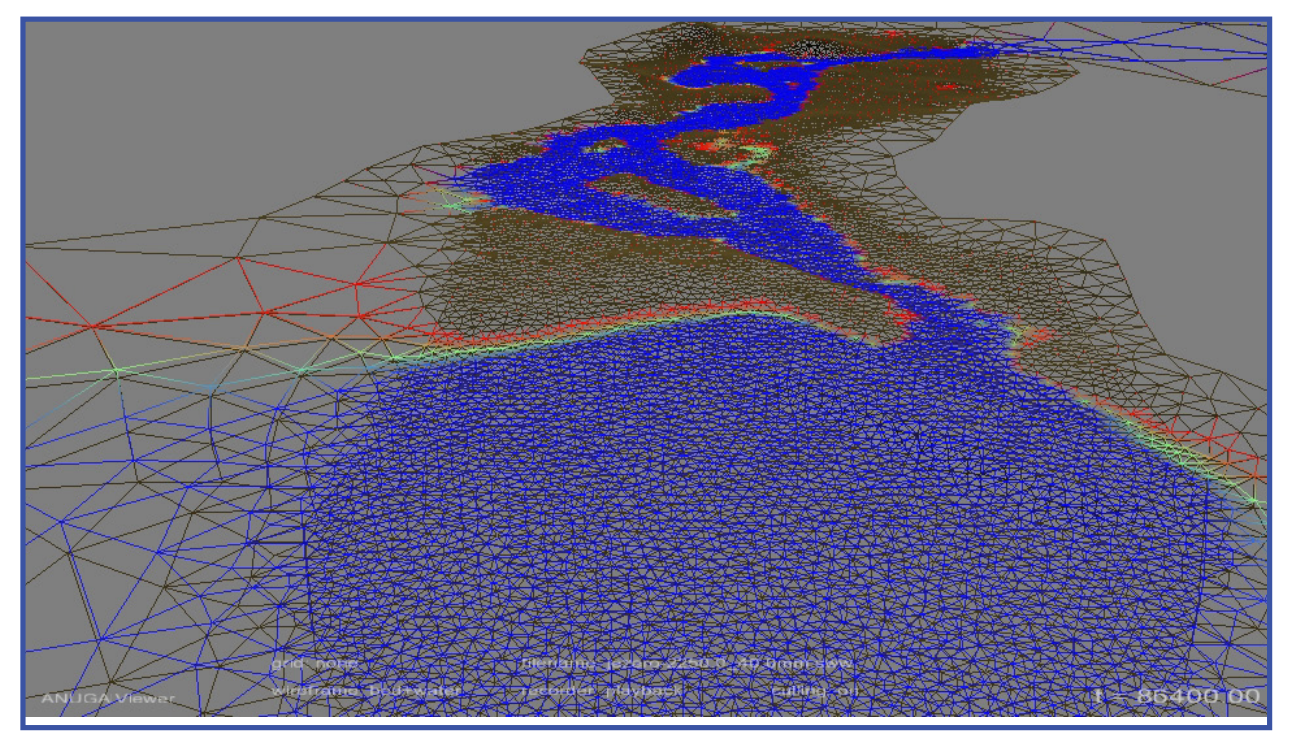


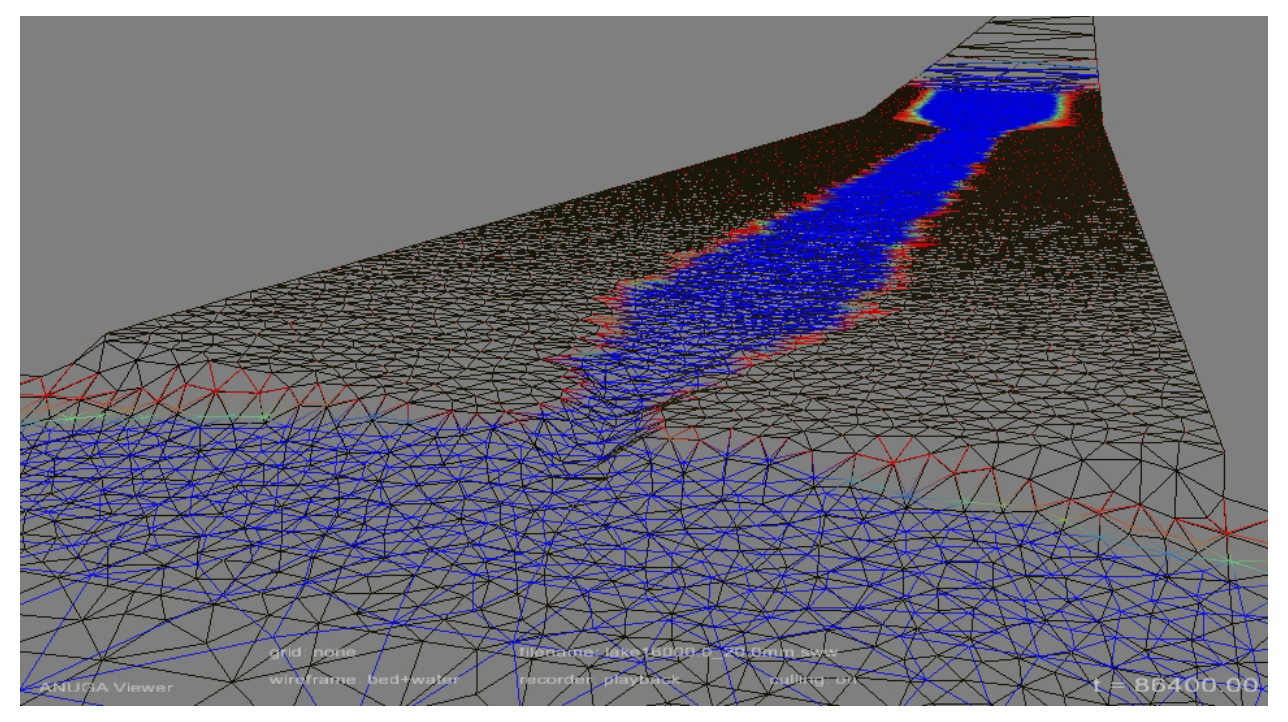
V. Modeling Methods

We have added several sediment transport operators to ANUGA Hydro [7] that calculates:

- Bedload: Standard approach [8] assuming sediment flux ~ excess shear stress to the 1.5 power. (This might be an underestimate of the shear stress-dependence in floods of this scale [9]).
- Suspension: Calculate entrainment rate following Dietrich (1982) [10]; settling by assuming a Rouse-like concentration profile [e.g., 11].

Other current assumptions: (1) one grain size, (2) a Darcy-Weisbach friction formulation, following [12], (3) suspended sediment that travels at the same velocity as the fluid, (4) spherical grains, (5) fluid momentum unaffected by sediment, (6) an artificial maximum sediment concentration of 30%, and (7) proscribed initial head (breach depth).



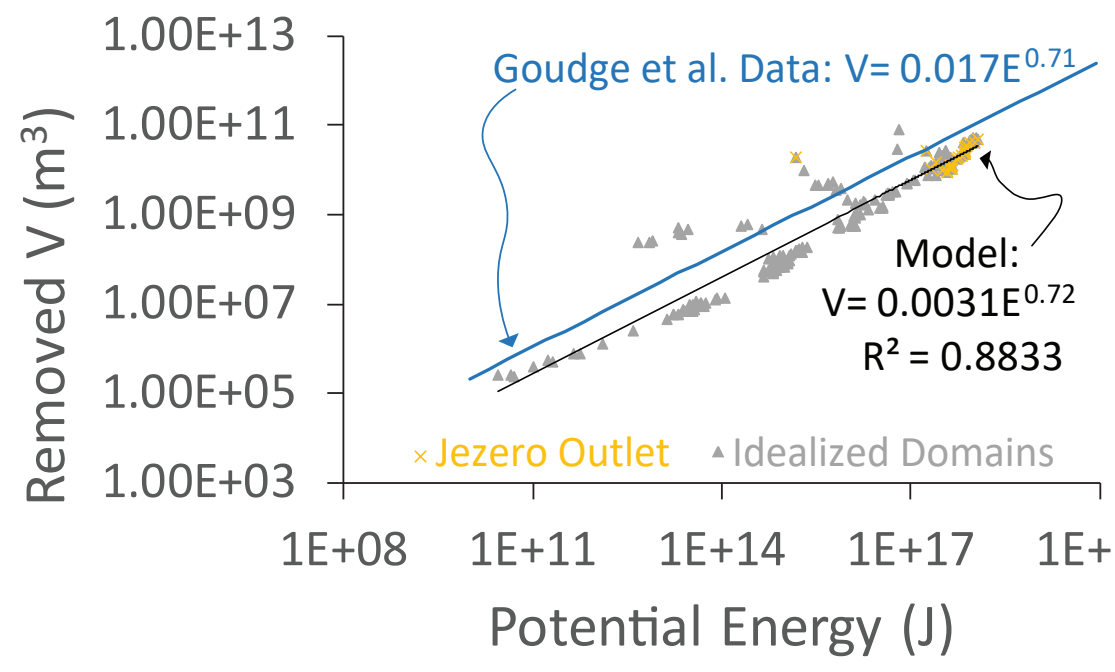


Initial experiments are parameter sweeps. Two examples, 1 day into flood: Jezero outlet (e.g., top, 4 cm grains) and an idealized domain (e.g., bottom, 16 km lake, 2 cm grains).

VI. Preliminary Modeling Results

Qualitative Observations:

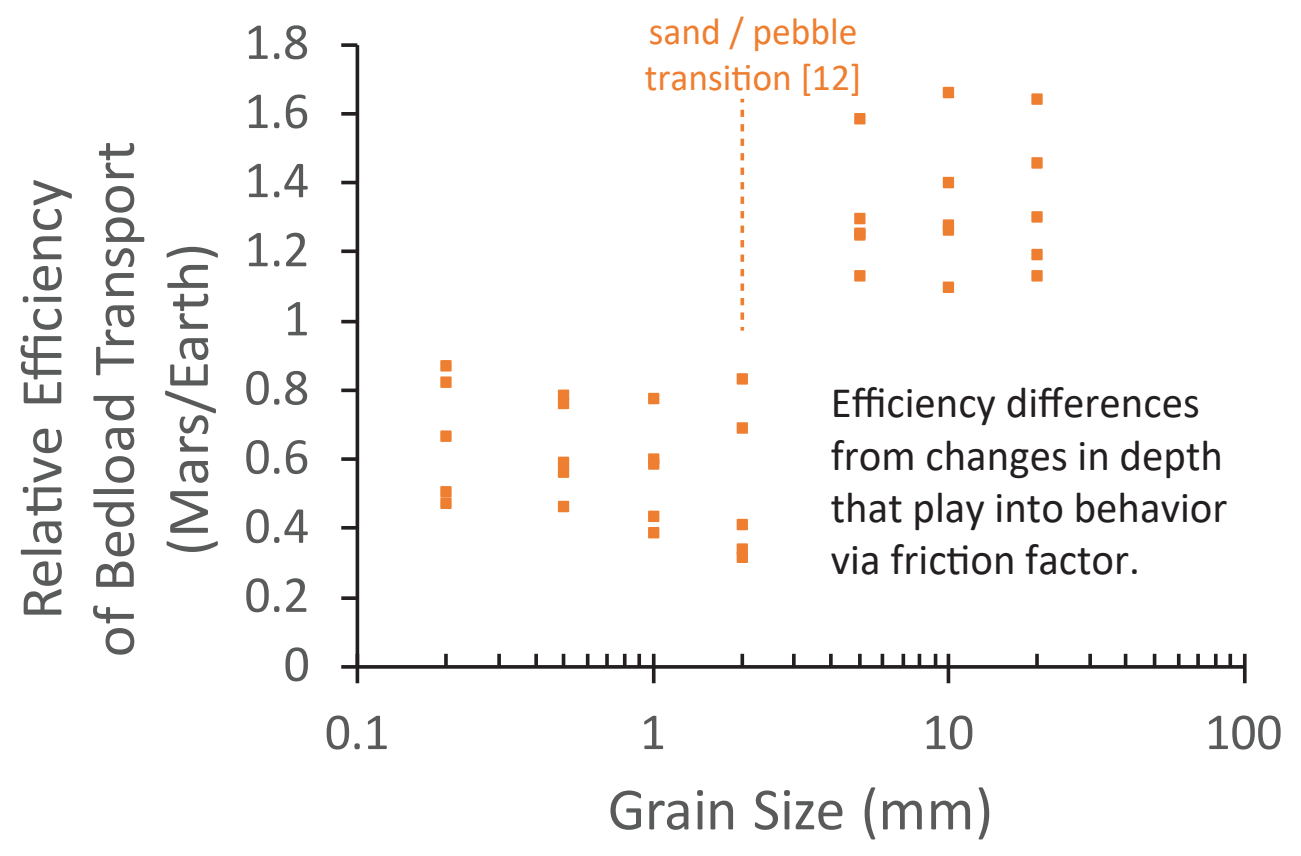
- As is observed both on Mars and in flume experiments [13], erosion occurs *inside* the draining lakes.
- We observe similar scaling relationships between potential energy of the flood and outlet volume as those observed in [6].
- Lake hypsometry and exterior slope are very important to the amount of erosion that occurs. Some cross-channel confining topography is needed to prevent outlet from widening and not entrenching.
- Grain density, porosity, model resolution, and initial breach assumptions do not have much influence on results.



Model vs. data in terms of scaling of energy to eroded volume.

Unexpected Sidelight:

- There are differences in the modeled relative efficiency for bedload transport on Earth and Mars.
- Apparently arises from difference in friction (i.e. flow depth vs. grain size).



Bedload experiments, different grain size: Mars vs. Earth (ratio of final outlet volumes)

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