EGU General Assembly 2020

EGU2020-12980_D1122

Bedrock Topographic Evolution from Rockfall Erosion

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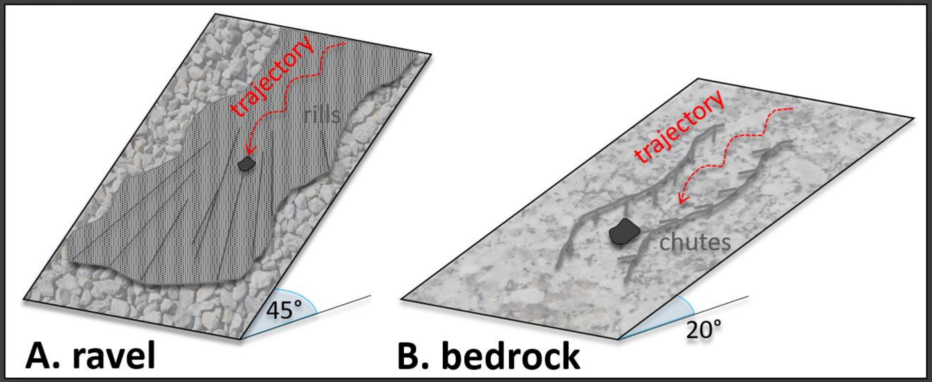
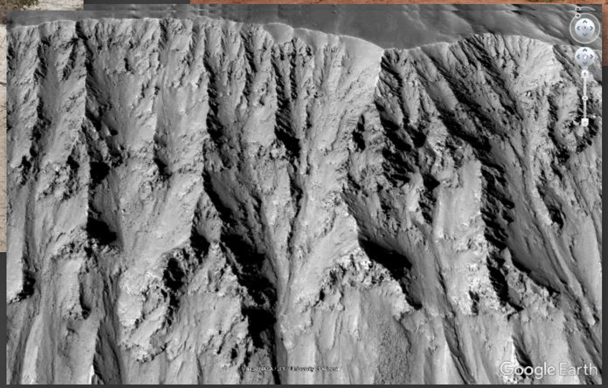




NSF
FNSNF Swiss National Science Foundation
NASA
California Institute of Technology 1891
Lamb surface processes group
ESD Earth System Dynamics Research Group

Background

- gravity moves **dry grains** or blocks downhill in rockslides and rockfall
- pebbles to large boulders saltate and impact on bedrock with **huge energies**

➢ boulder impacts into bedrock surfaces should cause significant bedrock **erosion**, likely shaping the **topography** even in the absence of water

➢ examples **landforms**: bedrock gullies on steep hillslopes, plinth surfaces on caprock-topped mesas, steep impact-crater slopes on planetary surfaces

➢ mechanistic models for fluvial and debris-flow incision exist, but similar **models for dry rockfall erosion** have not been evaluated

-> (How) does dry rockfall erosion shape rocky hillslopes?

Dry gravel erosion model

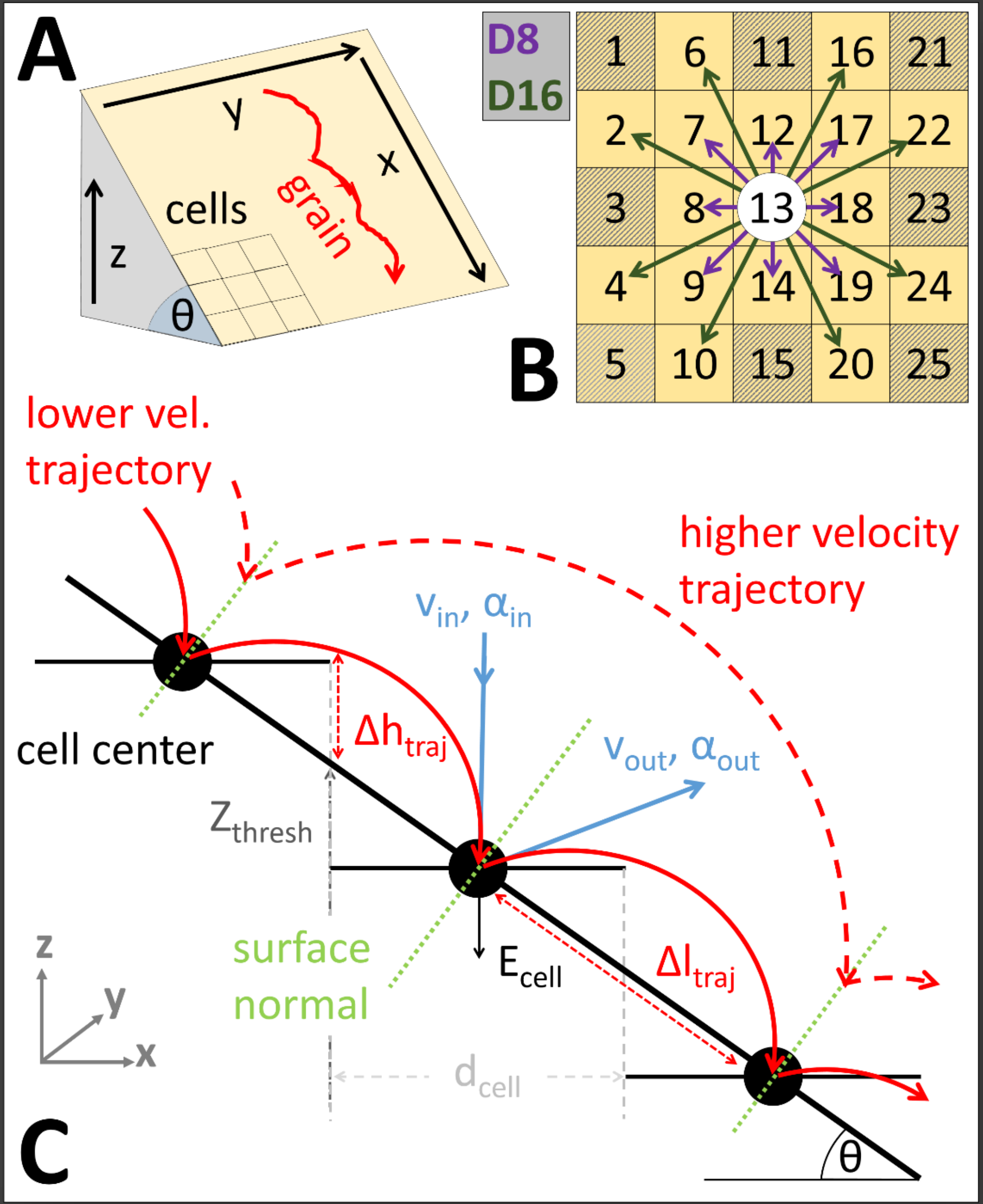
- discrete, cellular (**D16**) grain saltation trajectories
- **probabilistic** grain routing along dynamic 3D topo.
- **kinetic energy loss** due to gravel impacts
- calibrated bedrock impact **erosion volume** (~ σ_t)

Input

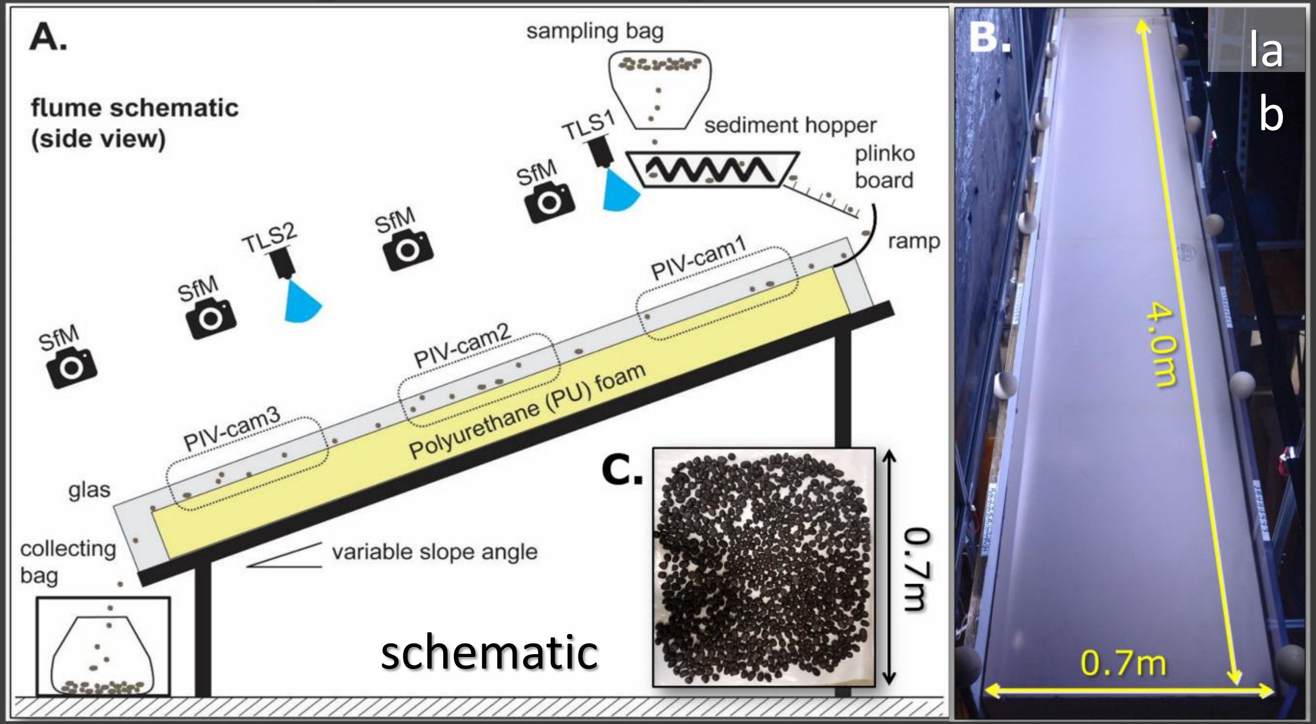
- DEM, grain source (size, mass, position, velocity)

Output

- grain trajectory statistics, eroded **topography**



Validation and calibration by lab experiments

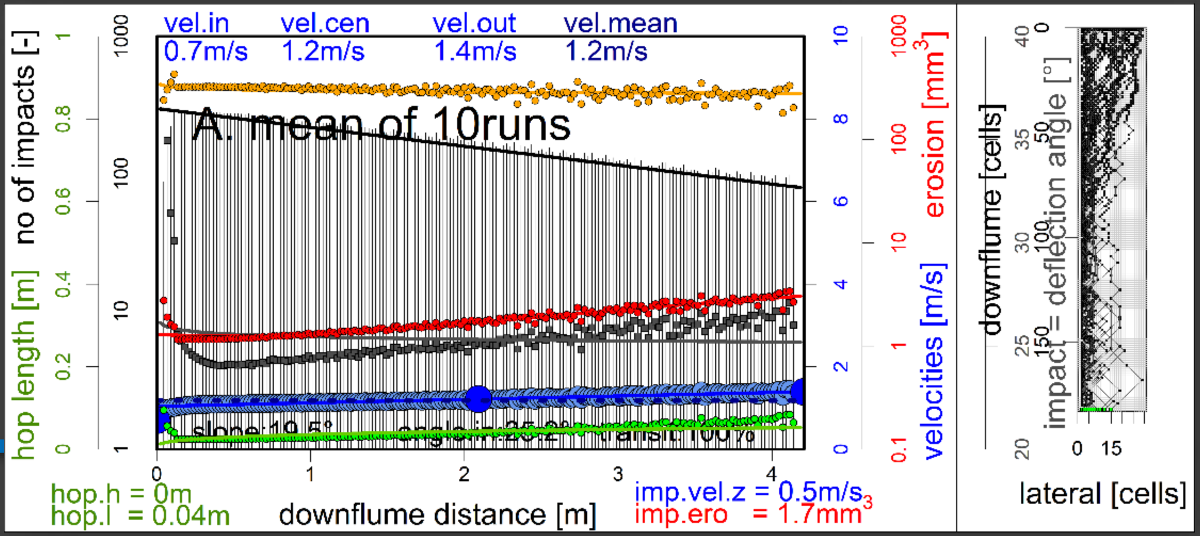


➢ lab experiments

- tilted **flume**, dry grain entrance from top
- lateral + vertical particle tracking by machine cameras (**PIV** at 100Hz)
- repeated spatial foam erosion surveys (**TLS** at mm-resolution)

➢ model-calibration

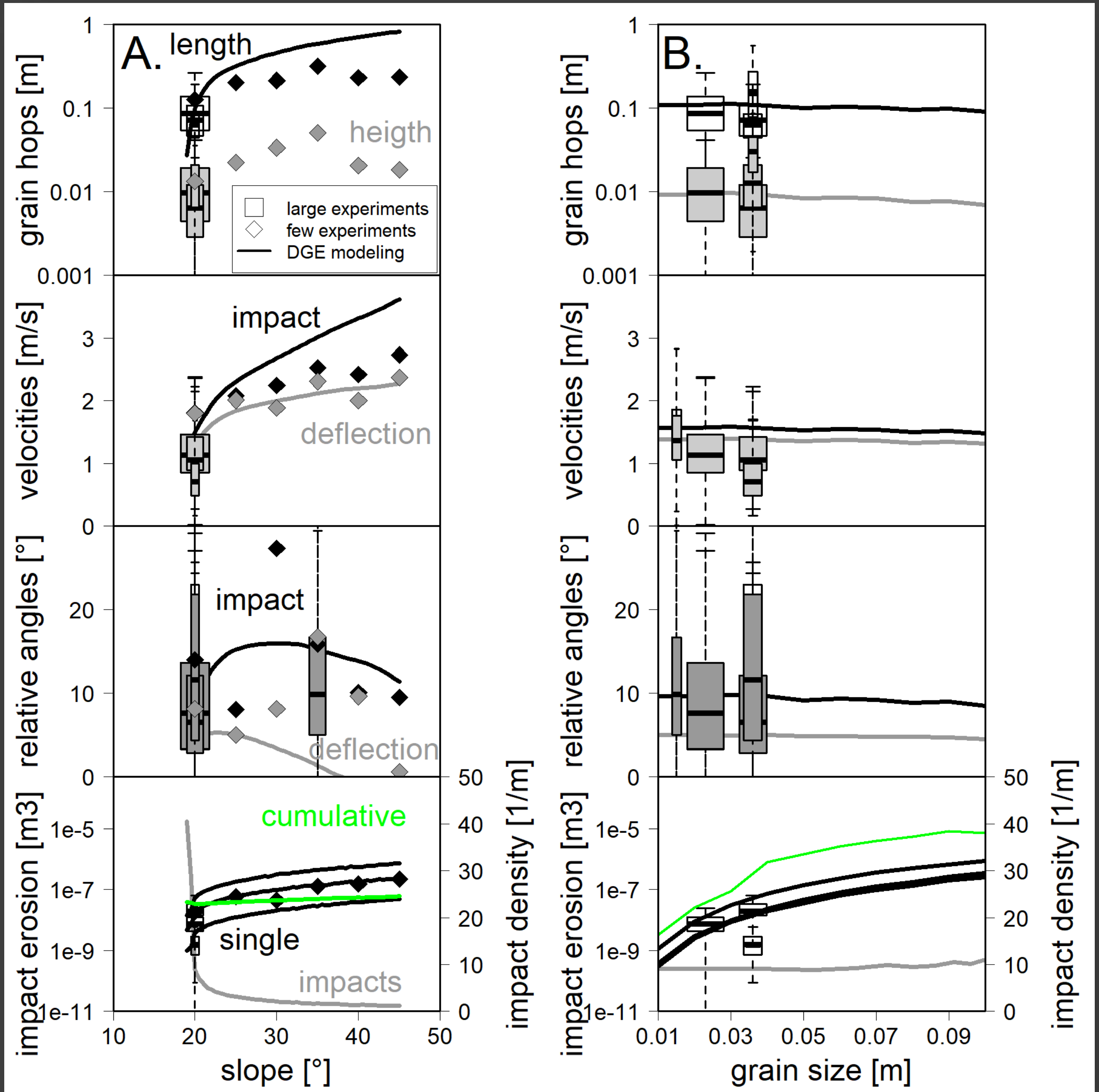
- **trajectories**: kinetic energy reduction by impact shock; stochastic hop directions
- **erosivity-factor**: mean value based on spatial abrasion / impact number



Erosion relations with slope and grainsize

preliminary results

- hop lengths + heights, and impact + deflection velocities only slightly **increase** with hillslope angle
- impact and deflection angles stay relatively **constant**
- **spatial erosion** increases by orders of magnitude both with increasing hillslope angle and grain size

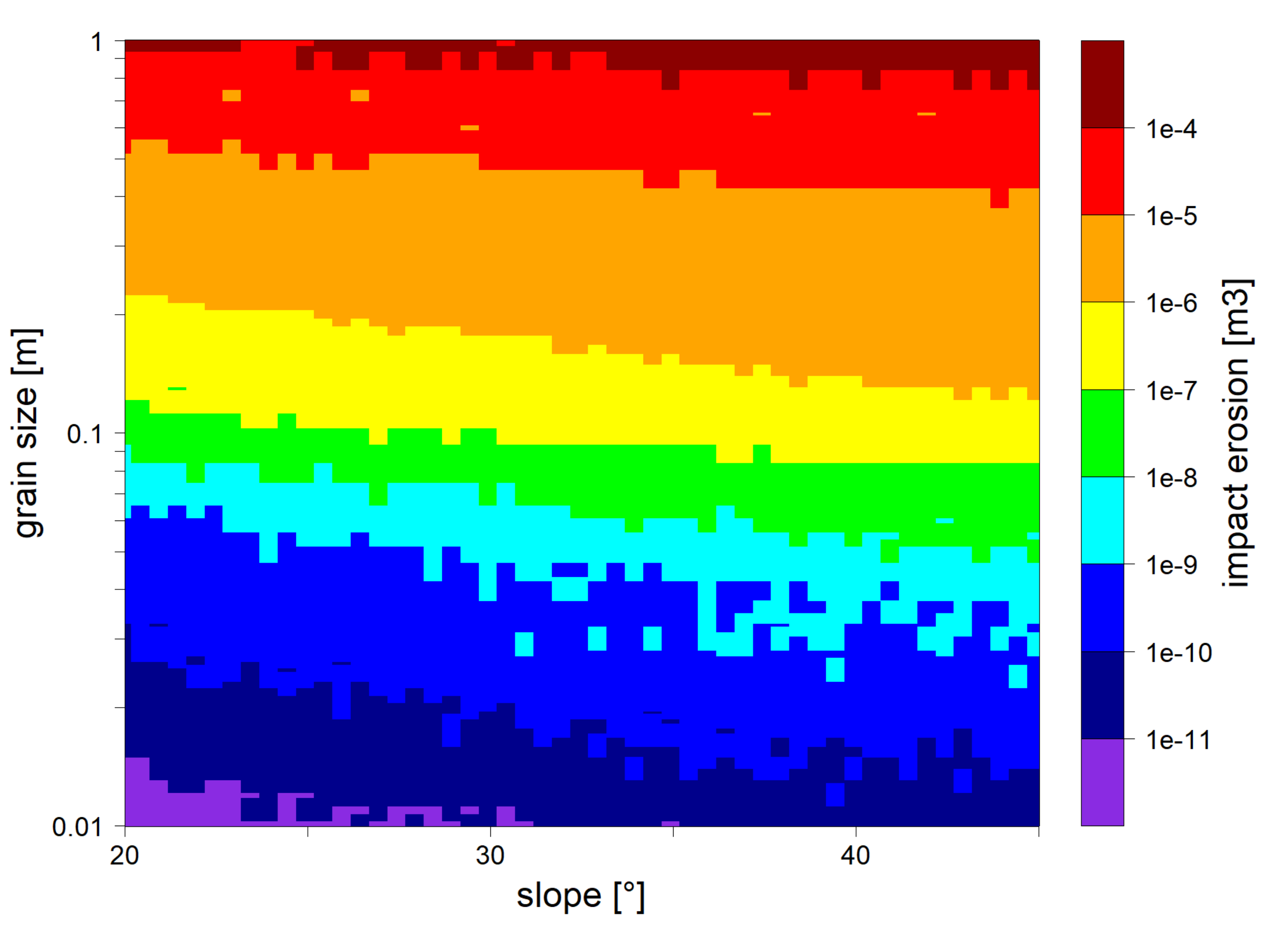


Dry rockfall erosivity space

preliminary results

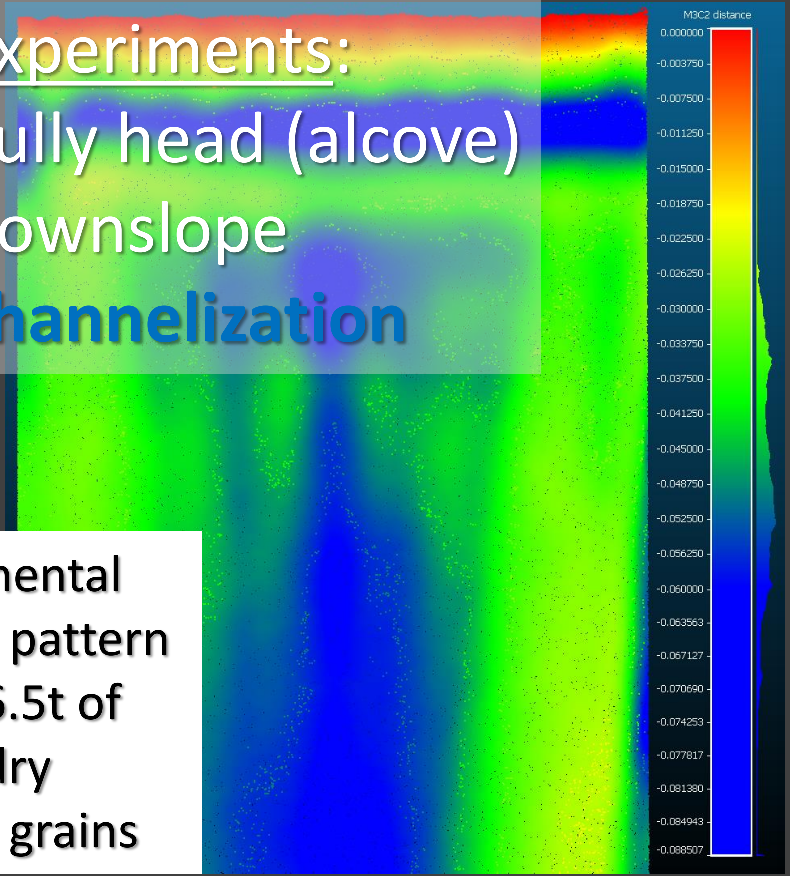
- assumptions:
  fixed erosivity and cell-size
  - **slope** has negligible influence on rockfall erosion for given grain size
  - **grain size** (mass) will drive topographic evolution

- still to be analyzed: (different) bedrock **erodibility** likely will result in spatial heterogeneity



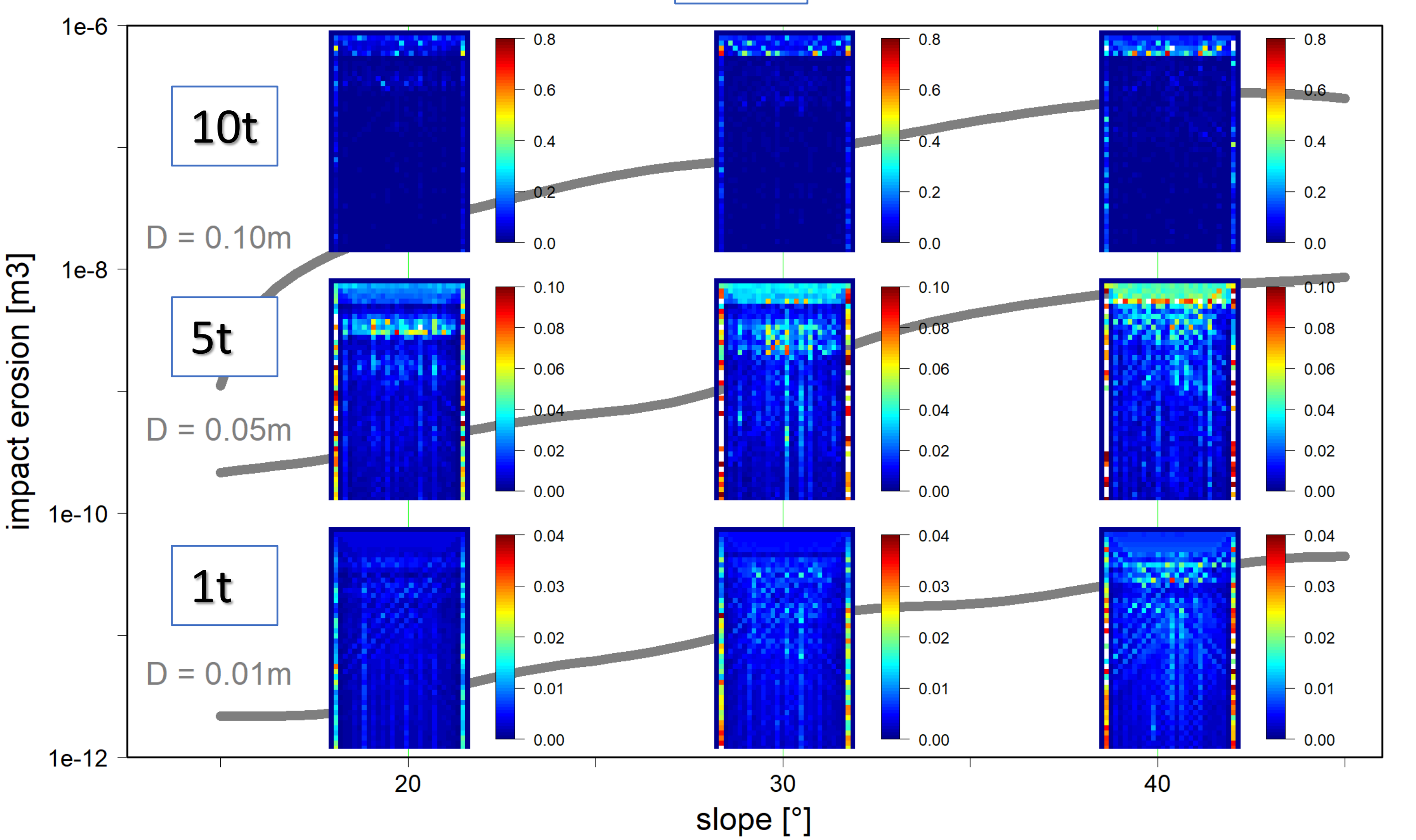
Evolving patterns of hillslope topography preliminary results

- experiments:
  - gully head (alcove)
  - downslope channelization



Experimental erosion pattern from 16.5t of 1.5cm dry Granite grains

Modelled erosion patterns from XXXt of rockfall



- modelling:
  - alcove formation pronounced by larger grains
  - channelization transiently grows downslope from hollow for smaller grains

Wrap-up and Conclusions

- experiments and model predict significant erosion by rockfall-driven **impacts**
- one large impact compared to several small ones of equal energy causes more topography, which can **steer** further (fluvially-driven) erosion
- transiently, **alcoves** (shell-shaped hollows) form at the dry rockfall entrance, eventually overdeepen and fill with talus, preventing further erosion (**cover**)
- farther downslope, topographic feedbacks drive rockfall into incipient **channels**, which cause those channels to incise resulting in **bedrock gullies**

-> rockfall impact is a feasible bedrock erosion process

-> active already at low slopes (< angle of repose)

-> can create channelized bedrock gully-topography