Geophysical Aspects of the 2018 Montecito Debris Flows

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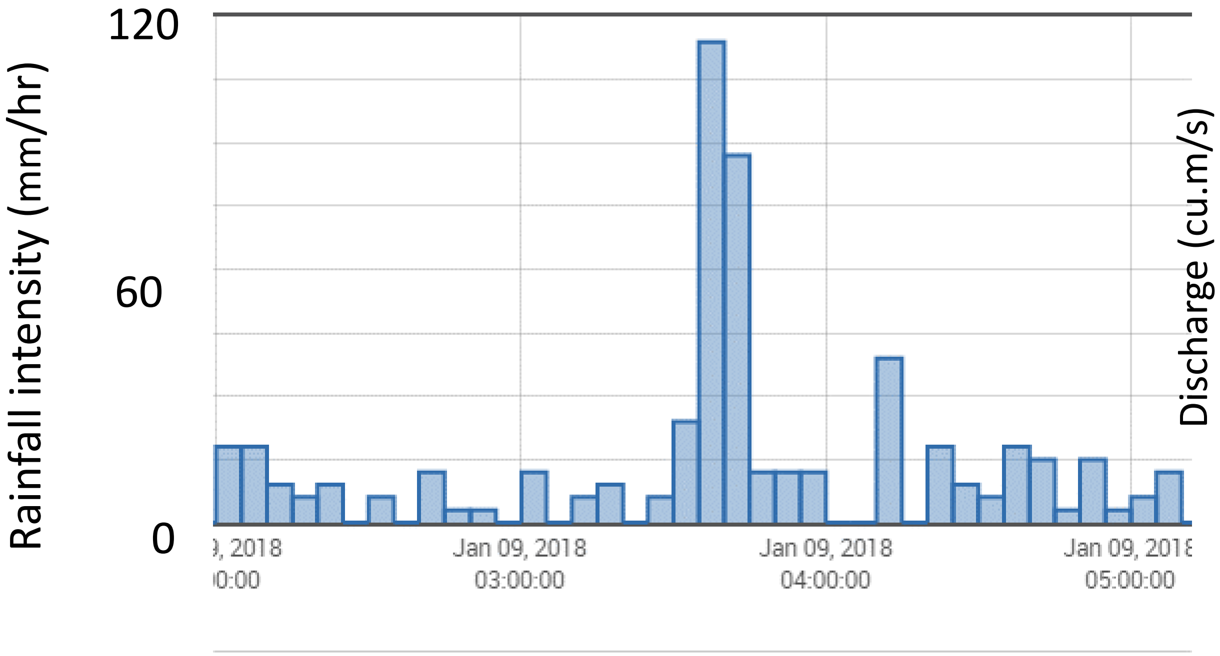
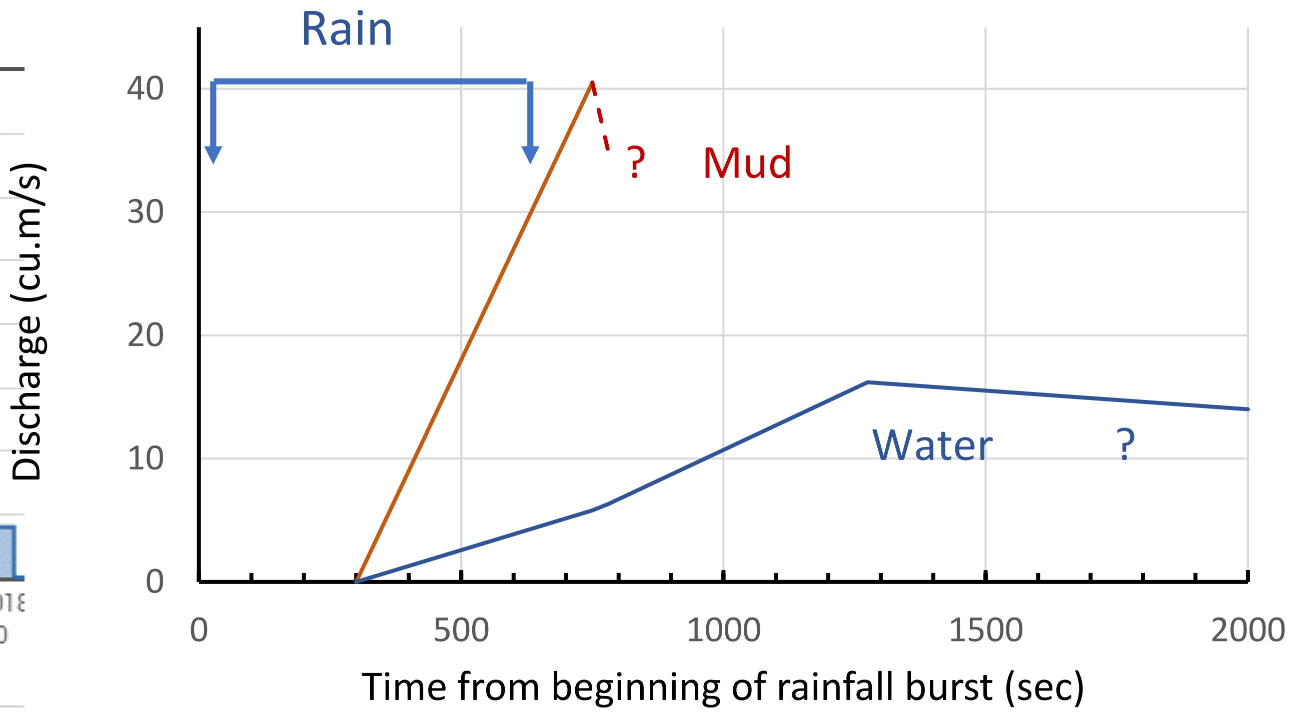
Montecito is built on debris-flow fans at canyon mouths

Santa Ynez Mts. after Dec., 2017 fire and intense rainstorm 21 days later

Intense, brief rainfall onto burned soil



"Conceptual" hydrographs for a 0.65 sq km tributary



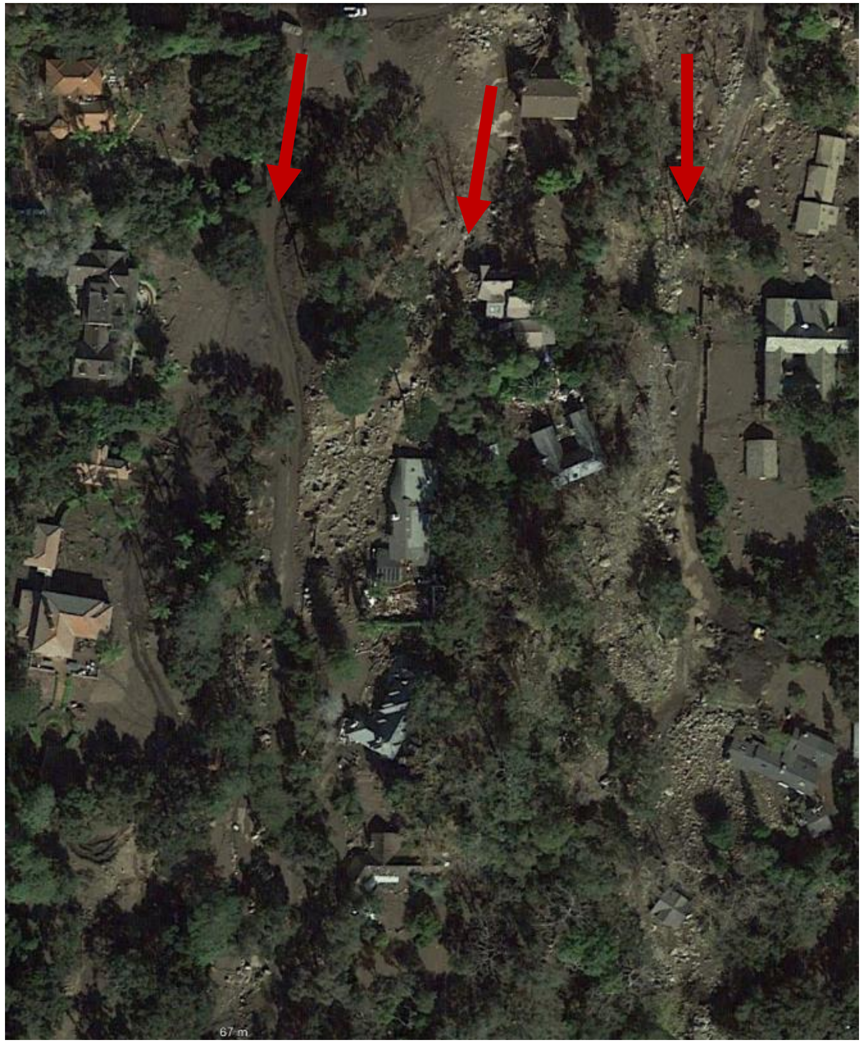
Sta. Barbara Co. RG at KTYD

Mountain canyons: bouldery alluvium scoured from entire channel networks

Mountain canyons: some boulders re-deposited by the flow in low-gradient or wide reaches; others too jammed and indurated to have been scoured

Boulders and 'mud' from 9 canyons spread 4-5 km across fans to sea level

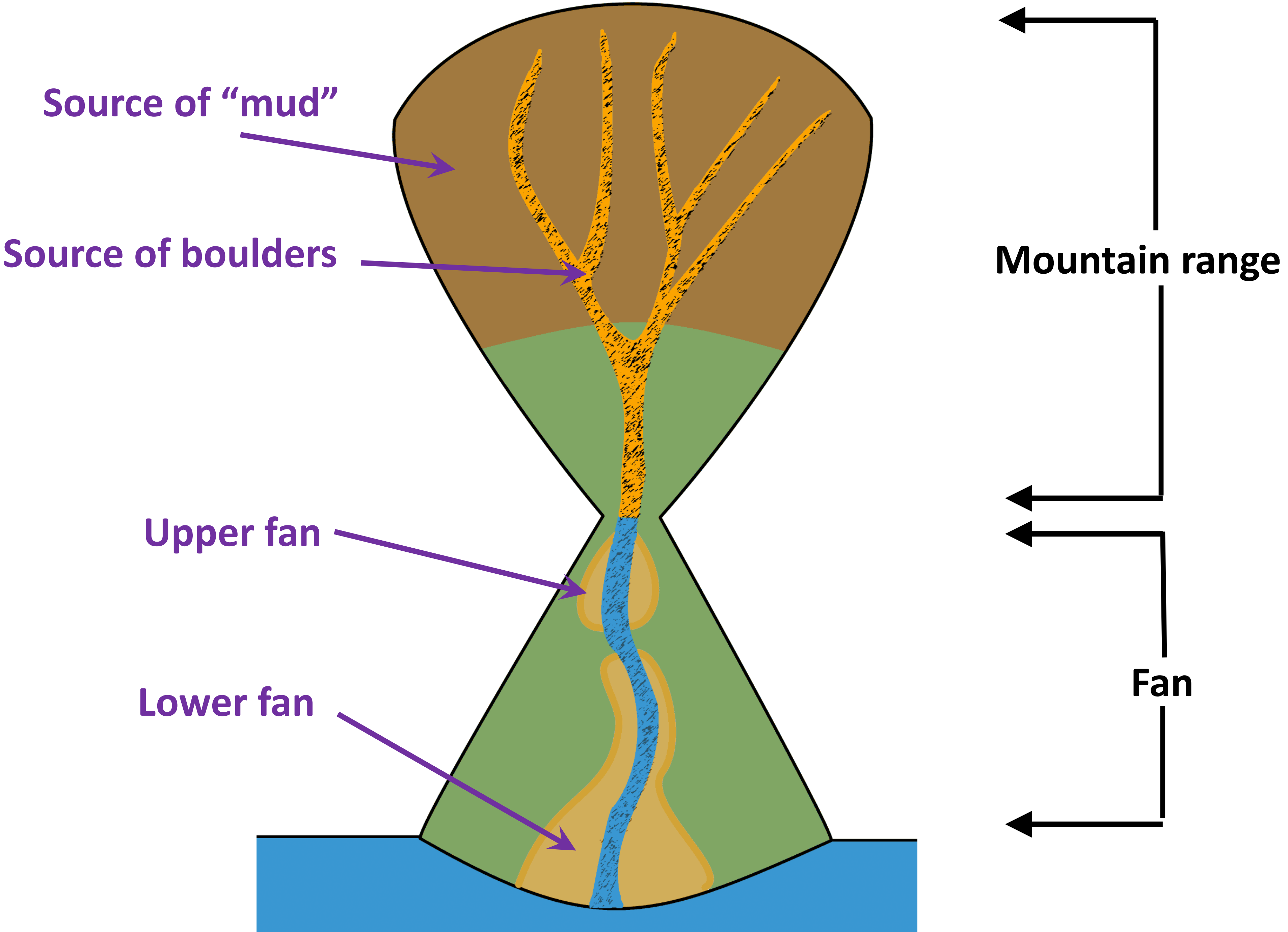
Boulders and ‘mud’ from 9 canyons spread 4-5 km to sea level



Google Earth

Significant mortality, destruction, and uncertainty about short- and long-term future risks

Domains of geophysical interest



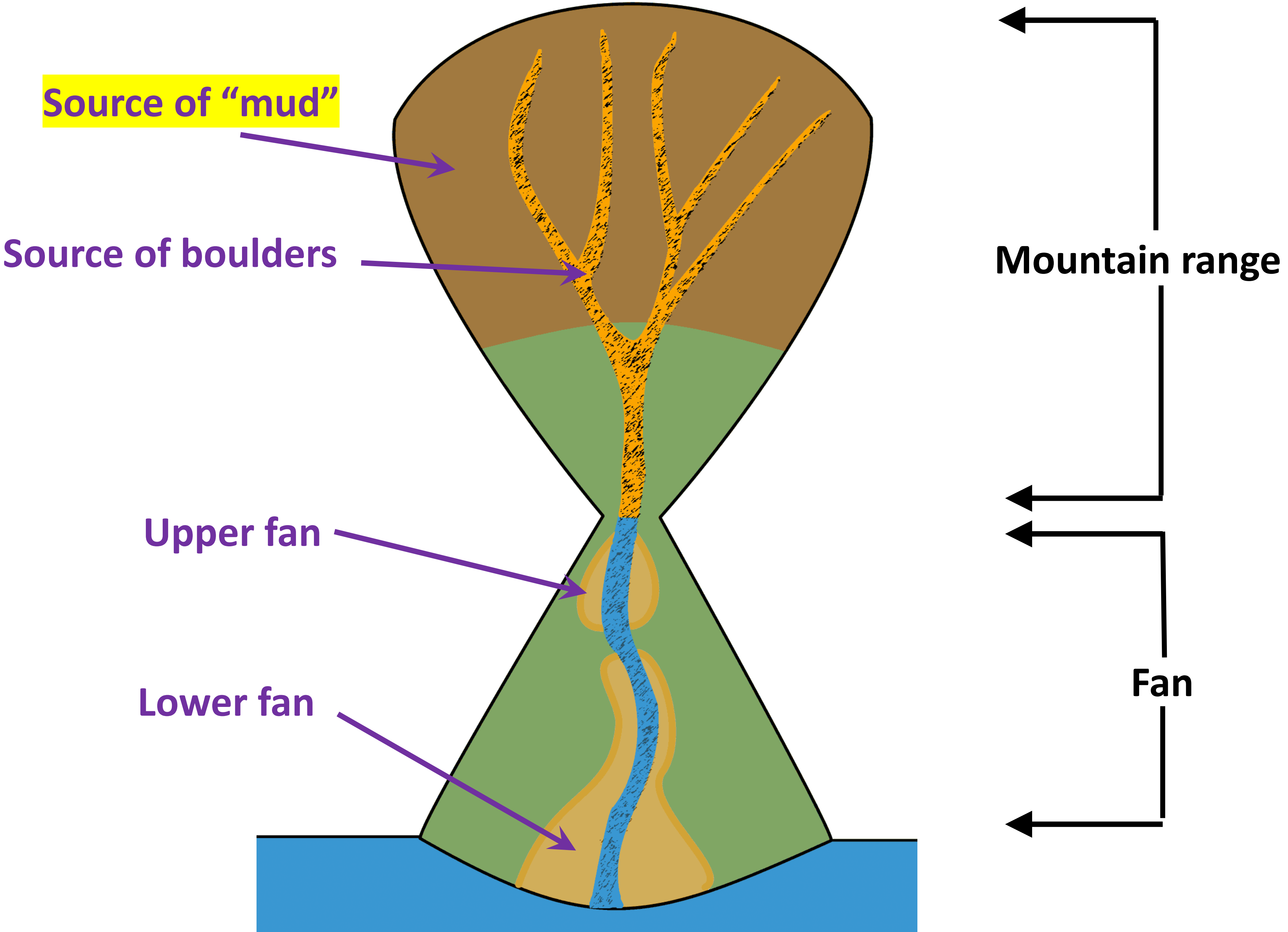
Geophysical questions

- How was the mud generated by the rainstorm?
- What were the flow properties of the material thus generated?
- How did the generation and flow properties cause the debris-flow to mobilize so many large boulders?
- What controlled the dispersal of the boulders?

Data

- Lidar before and after debris flow
  - Topographic characteristics
  - Scour and deposition volumes
  - Sediment source definition
- High-resolution color aerial photography for SfM
  - Sediment source definition
- Hi-resolution rainfall intensity
- Field surveys
  - Flow elevations from range-top to sea level for depth, velocity, discharge and gradient
  - Super-elevations on trees for local flow velocity patterns
- Material characterization
  - Residual deposit depth (field and lidar)
  - Matrix deposit grain size and bulk density
  - Rheology (lab and field-interpreted)
  - Boulder distributions and sizes
- Eye witness and instrumental records
  - Flow arrival times
  - Flow nature

Domains of geophysical interest



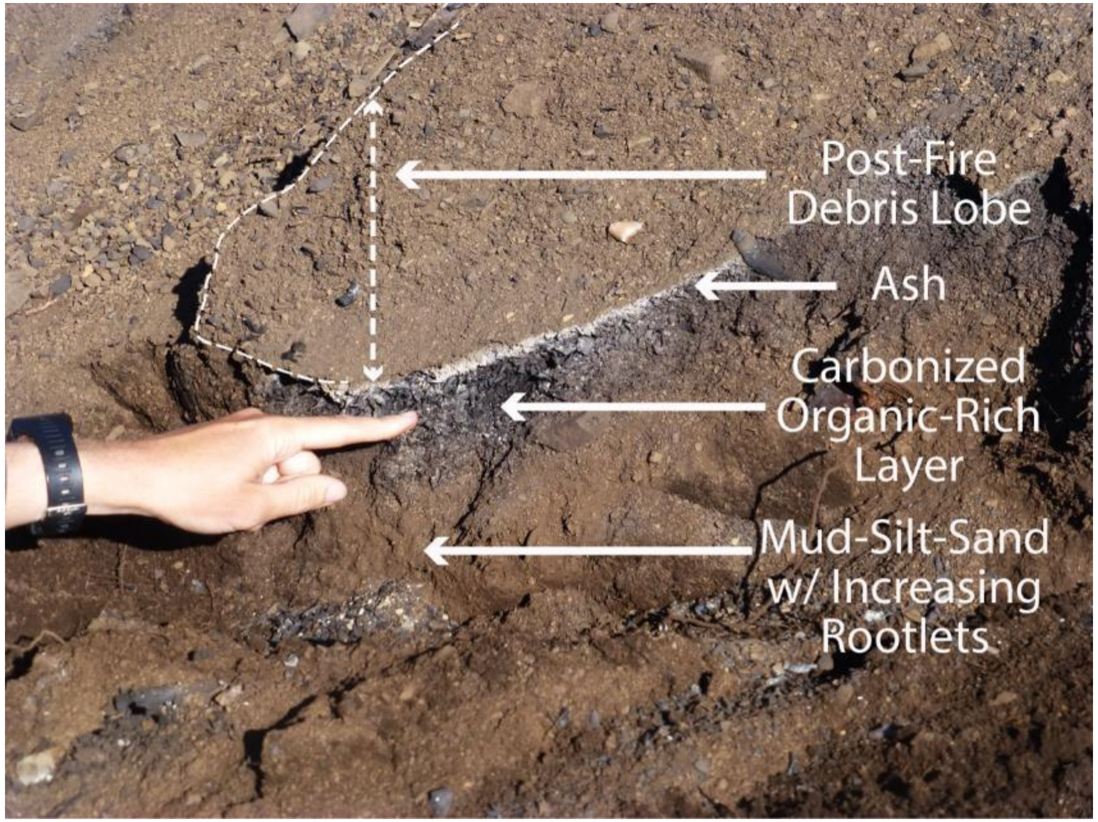
Lithological effect on initial mobilization of 'mud'

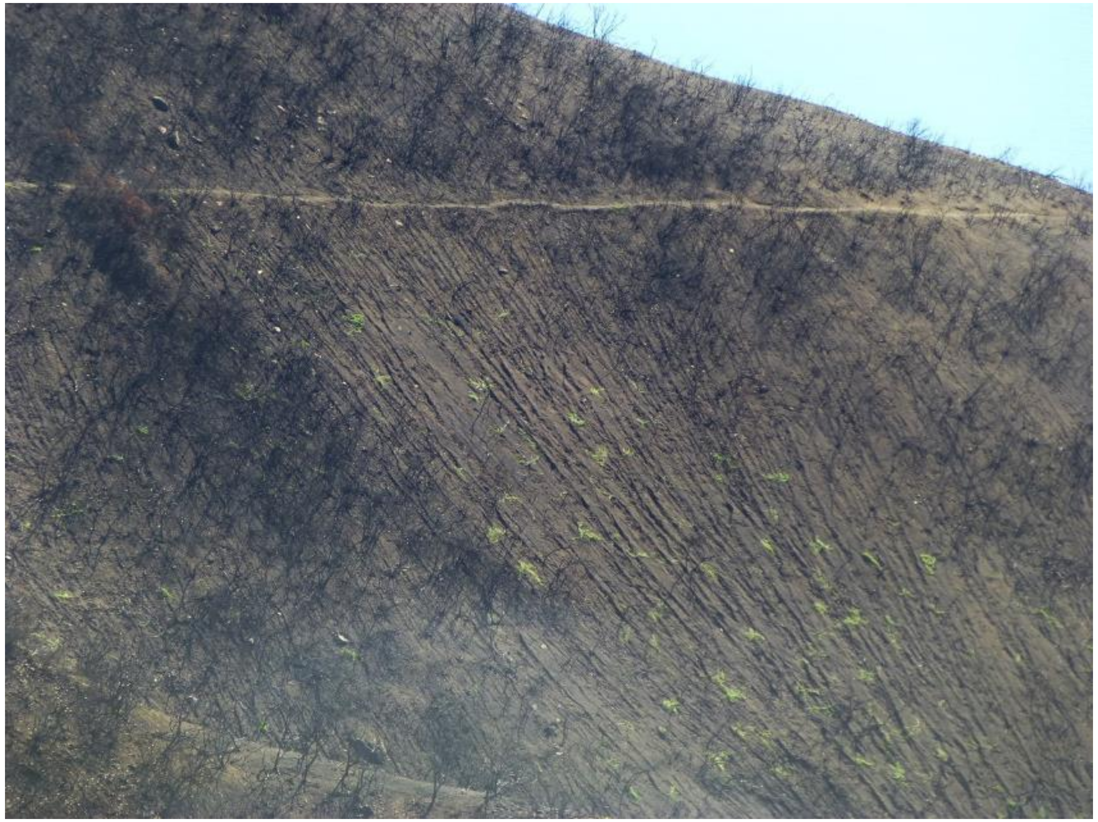
Sandstones: collapse of saturated colluvium on unrilled slopes and in gullies

Shales: rilling of fine-grained soils by overland flow

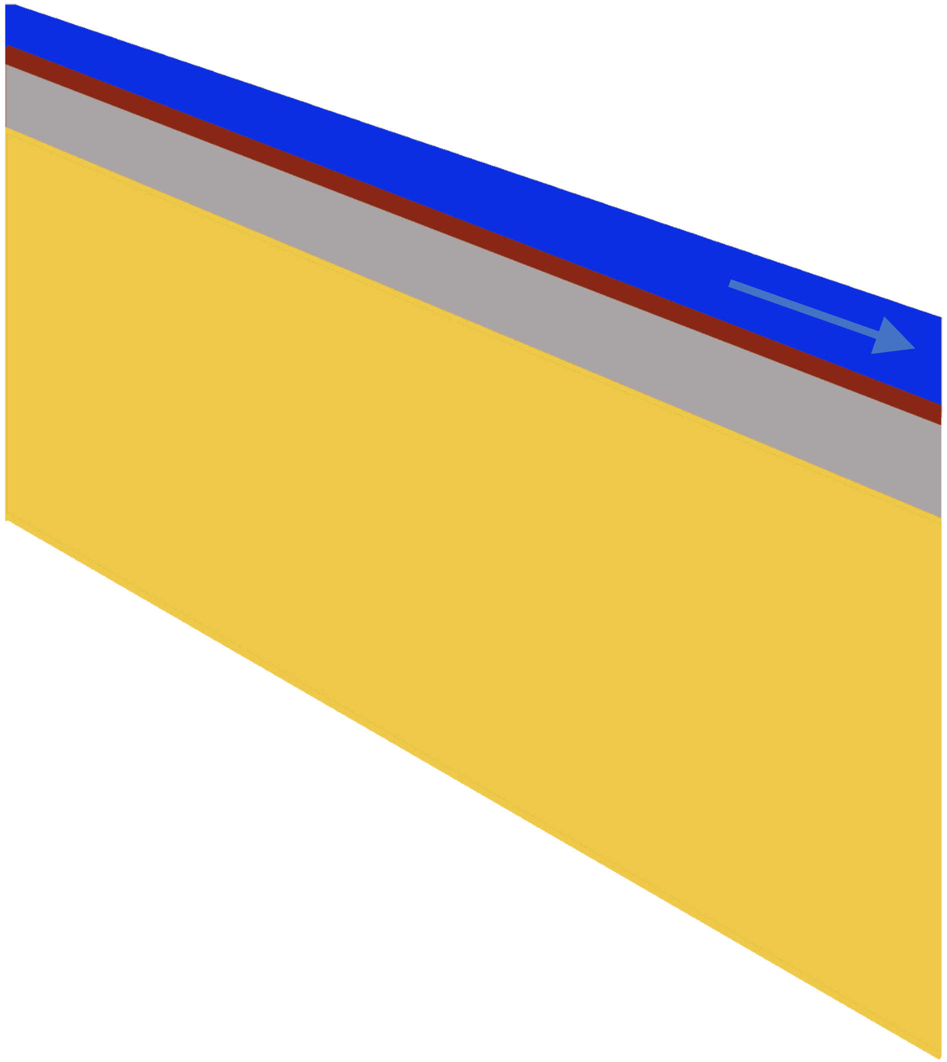
Main source of mud was on shale formations:

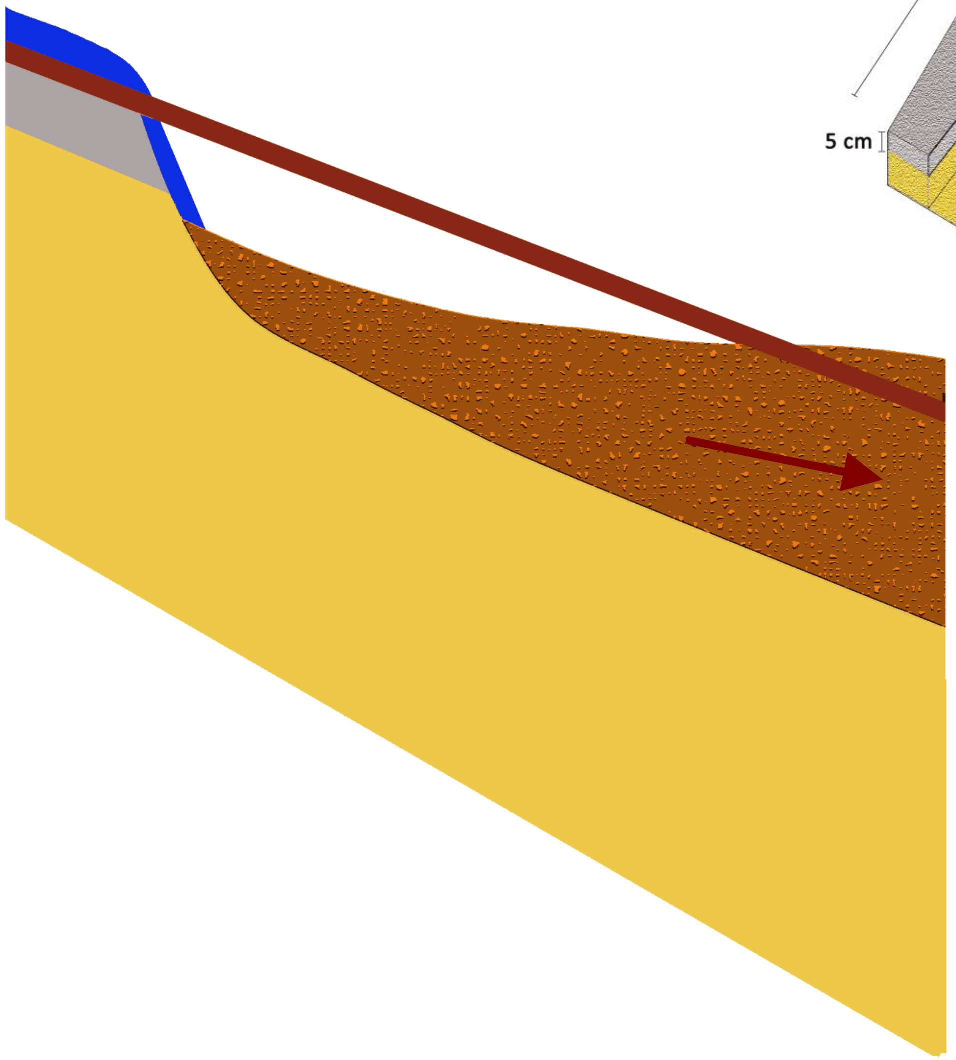
--- rills formed by overland flow driven by intense rainfall on burned soil

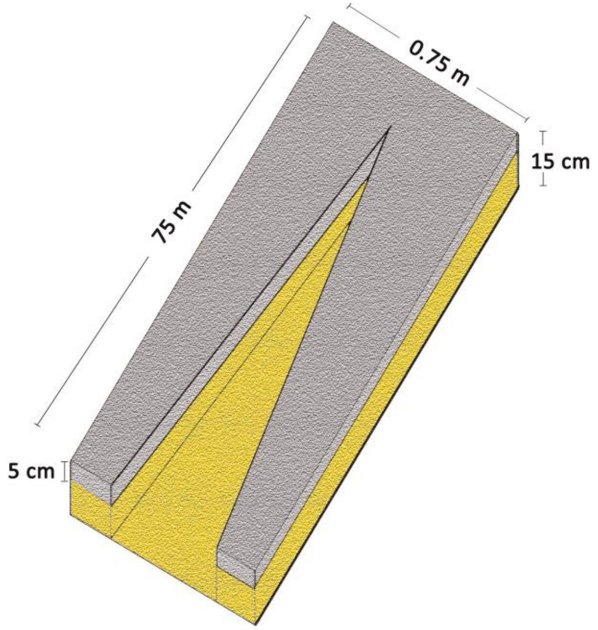

Post-Fire
Debris Lobe
Ash
Carbonized
Organic-Rich
Layer
Mud-Silt-Sand
w/ Increasing
Rootlets



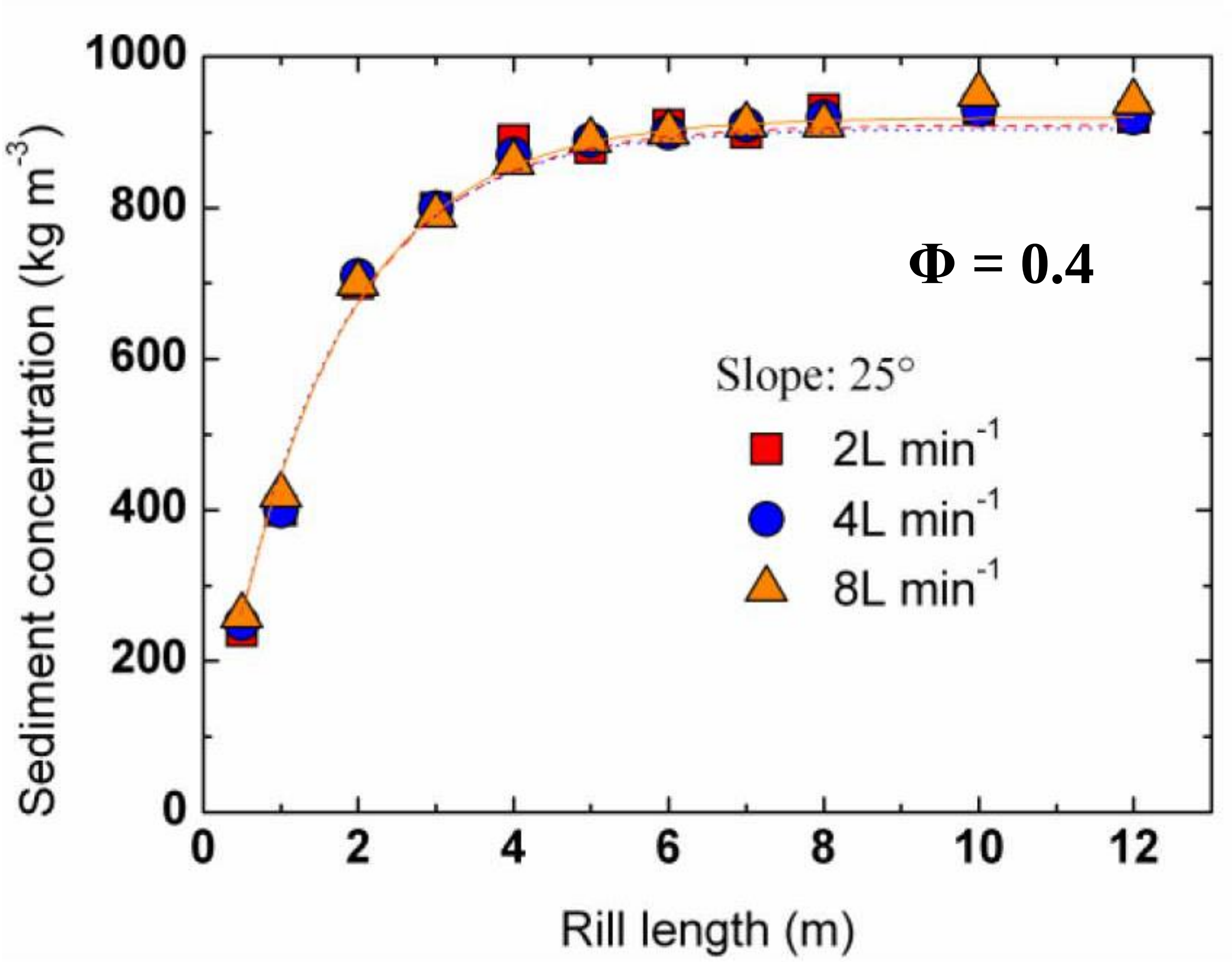
Incision of rill and formation of mud





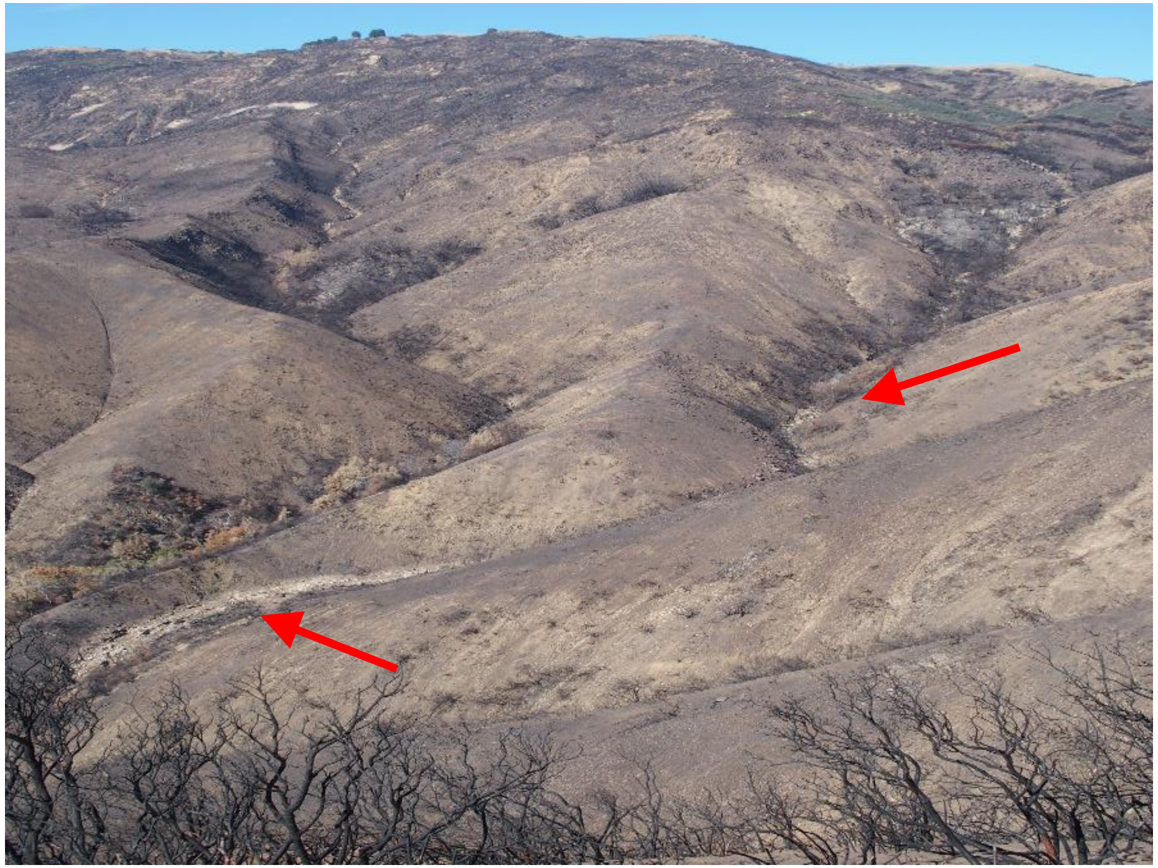


Experimental evidence for increasing sediment concentration in flows along a rill on a steep slope, but mechanism poorly understood.

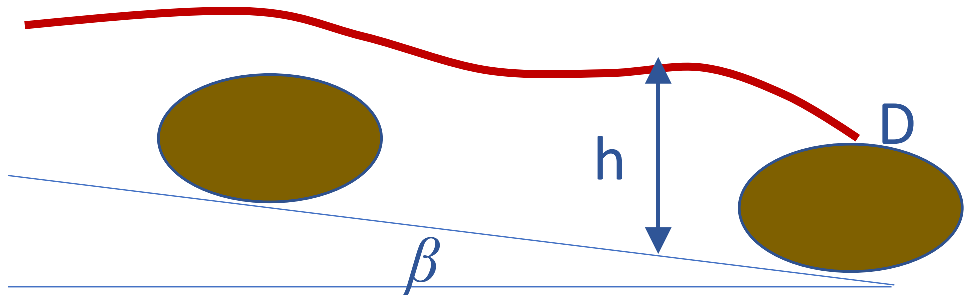


Chen et al. (2014) PLOS One

Field evidence that mud generated on hillslopes caused boulders to be scoured from even the smallest, upstream-most channels.



Boulder entrainment: force balance



$$\frac{1}{2} C_D \rho_f A_s u^2 \;+\; F_g \sin\beta \;+\; k\,\rho_f\, V_s u \frac{\partial u}{\partial x} - F'_g \cos\beta \mu_f = 0$$

Drag　　Gravity d/s　　Impulse　　Friction

Muddy matrix ($\rho_s \approx 2000\ \mathrm{kg/m^3}$) lowers F'_g, μ_f

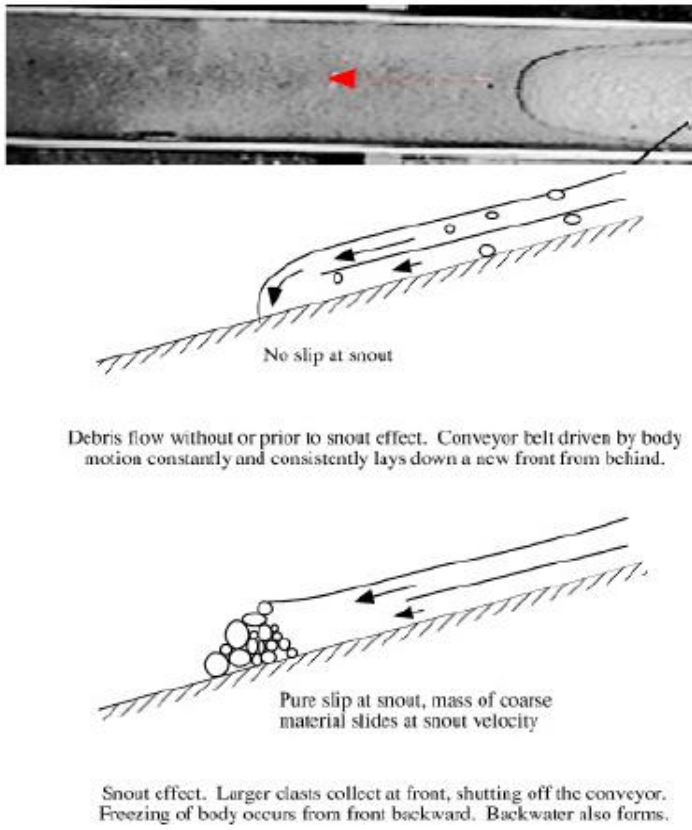
Lift force can be significant if a boulder is large but immersed:

$$F_L = \frac{1}{2} \rho_f A_s C_L \left(u_t^2 - u_b^2\right)$$

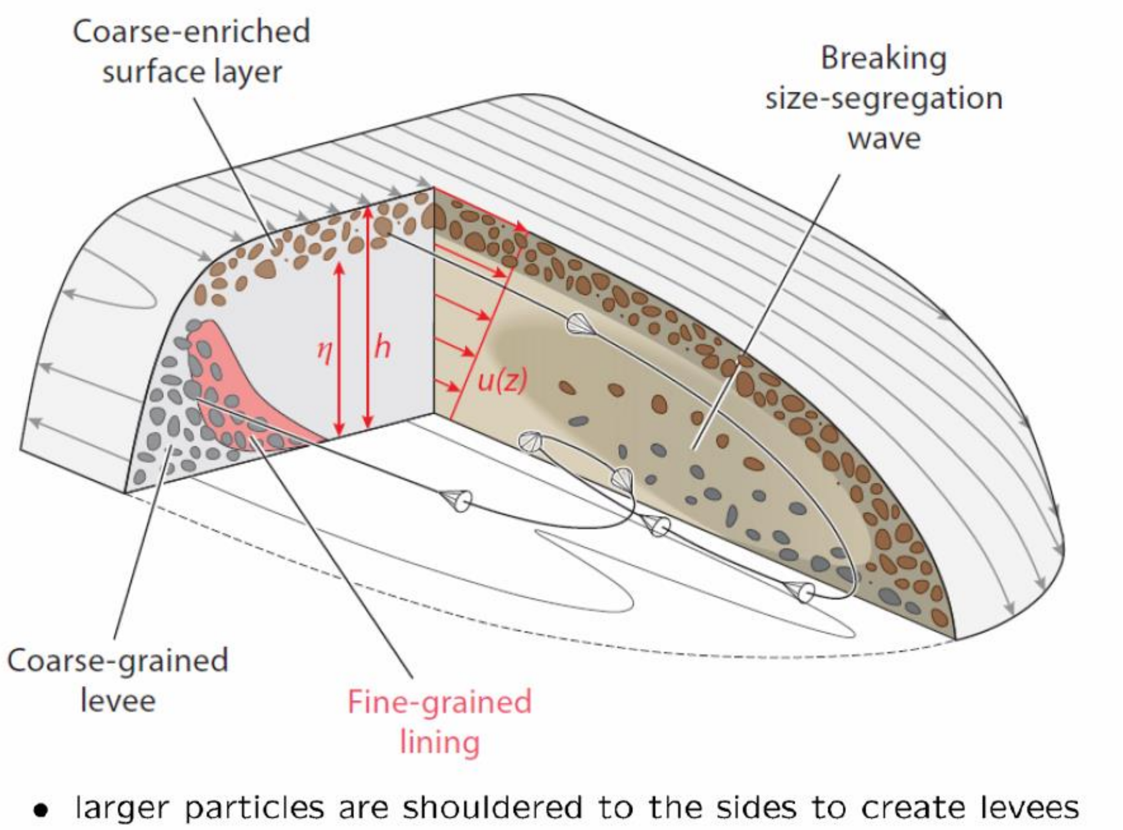
Velocities (cross-sectionally averaged and local) from mudline super-elevations

Upon leaving the canyons, peak flows exceeded channel conveyance capacities and carried some very large boulders

Transport and sedimentation in channels and on fans



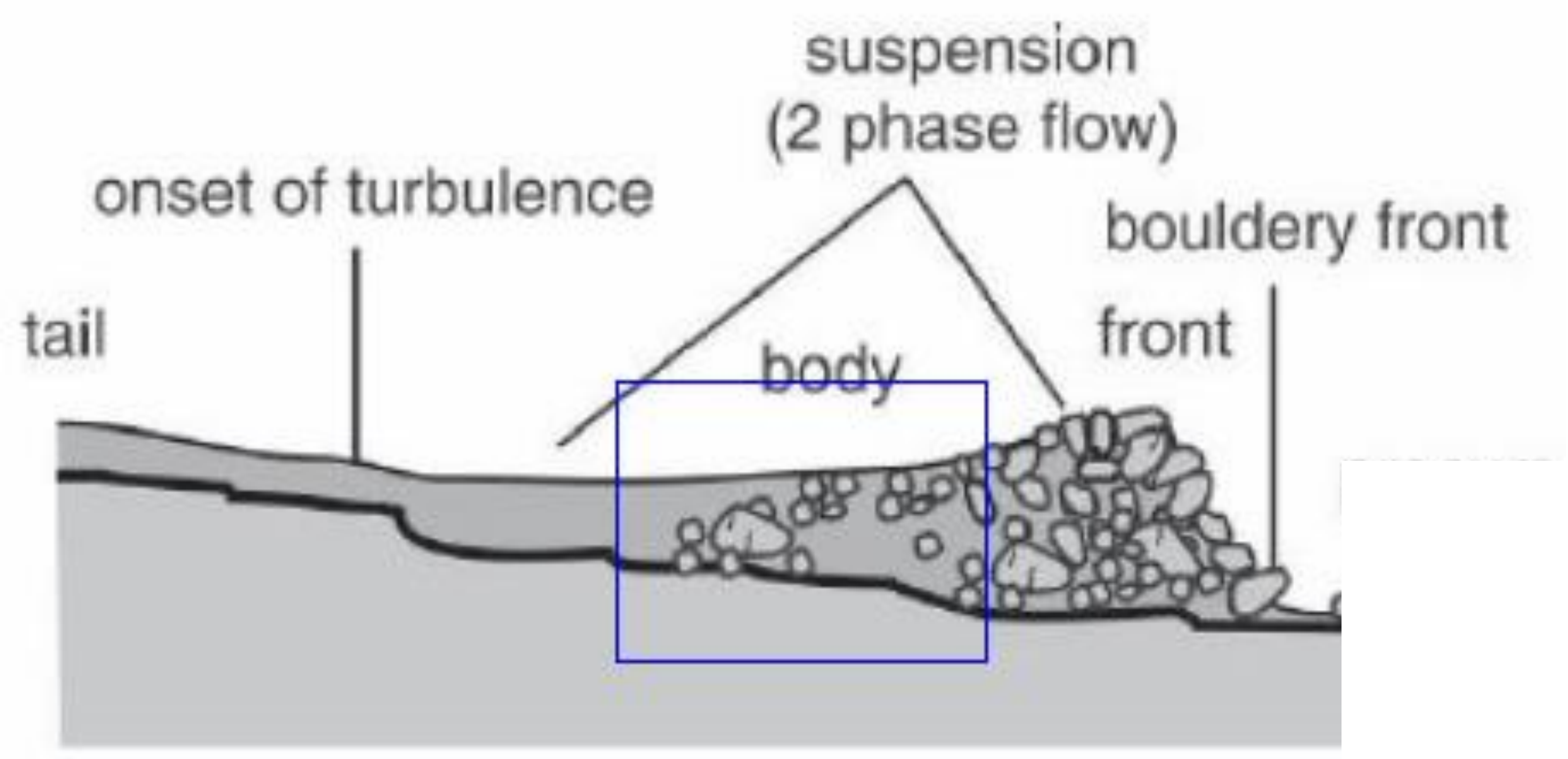
Parsons et. al (2001) J. Geology.



Gray, J. M. N. T. (2018) Ann. Rev. Fluid Mechanics

Boulder accumulations and size distributions mapped

Resulting conceptual model of debris flow form and behavior gradually being verified by eyewitness accounts (+/- security videos)



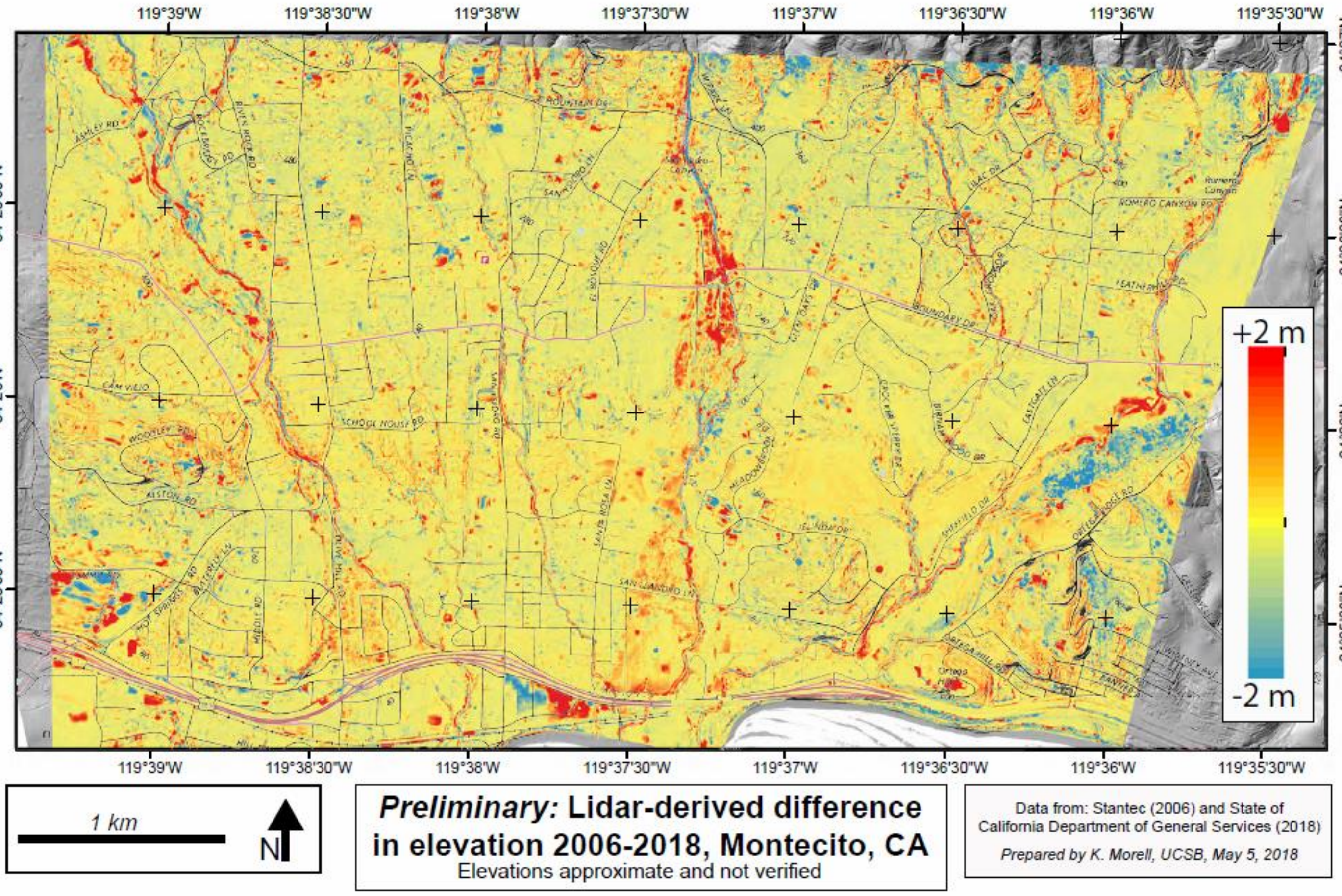
Flow deposits on upper San Ysidro fan

Field estimates of speeds, depth, and particle size agree consistent with theories of highly frictional, collision flow

Flow deposits on lower San Ysidro fan

Field estimates of speeds, flow depths, and particle sizes < 1 mm consistent with "macroviscous" flow behavior with a low yield strength and viscosity dependent on sand-silt-water content

Fan accumulation from lidar differences combined with field measured residual deposit thickness and grain size



Over-fan flow depths decreasing down fan

Summary

- Patterns of flow characteristics, scour-fill, and deposits emerging from field surveys
- Still much to explain
- Some mechanisms not yet understood (mud generation; boulder segregation)
- No single agreed-upon constitutive equation for debris flows and for how it/they might be affected by material composition and therefore initiation mechanism.
- Makes assessment of recurring hazard difficult.