

Probing the micromechanical features of a fracture interface using a multi-physics approach:

A numerical investigation relating asperity deformation with fluid flow



Clay
Wood



Chun-Yu
Ke



Andy
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Jacques
Rivière



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Elsworth

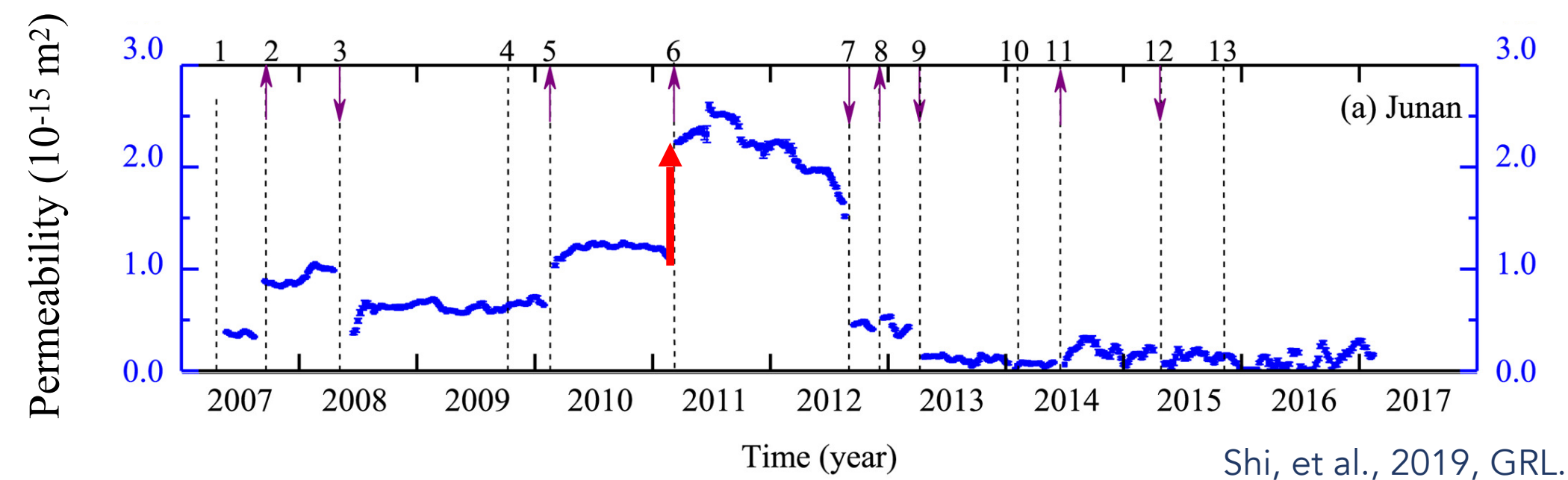
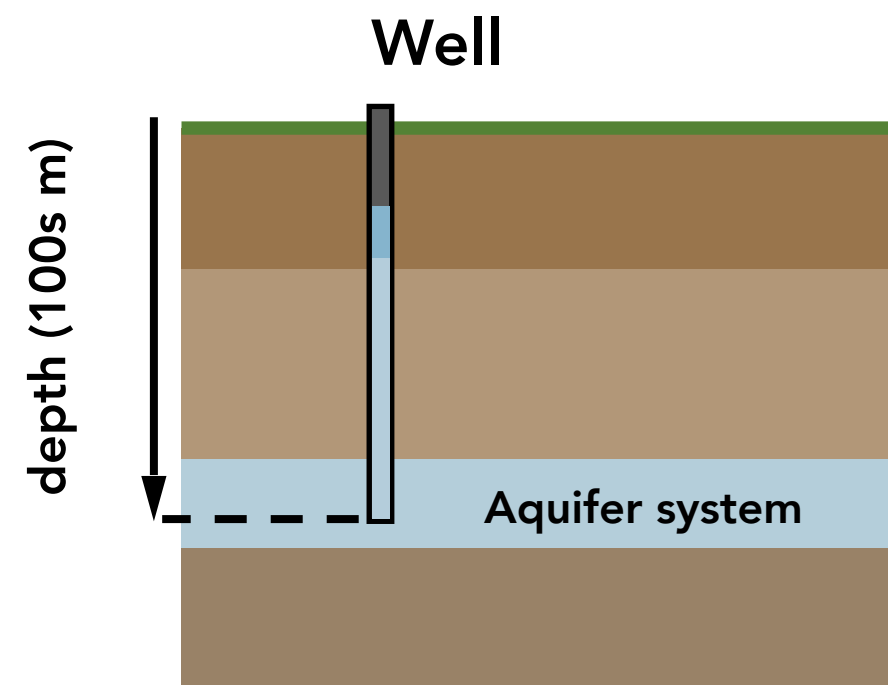


Chris
Marone



Parisa
Shokouhi

Field observations show that seismicity (dynamic stressing) induce transient changes in elastodynamic and poromechanical properties

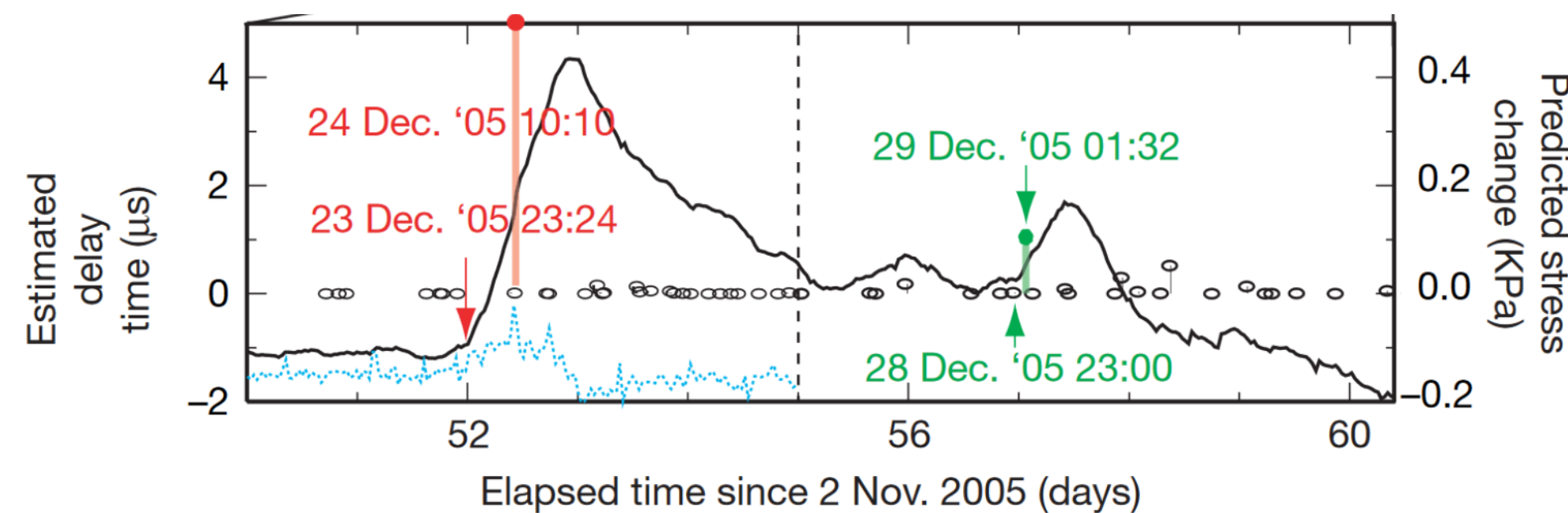
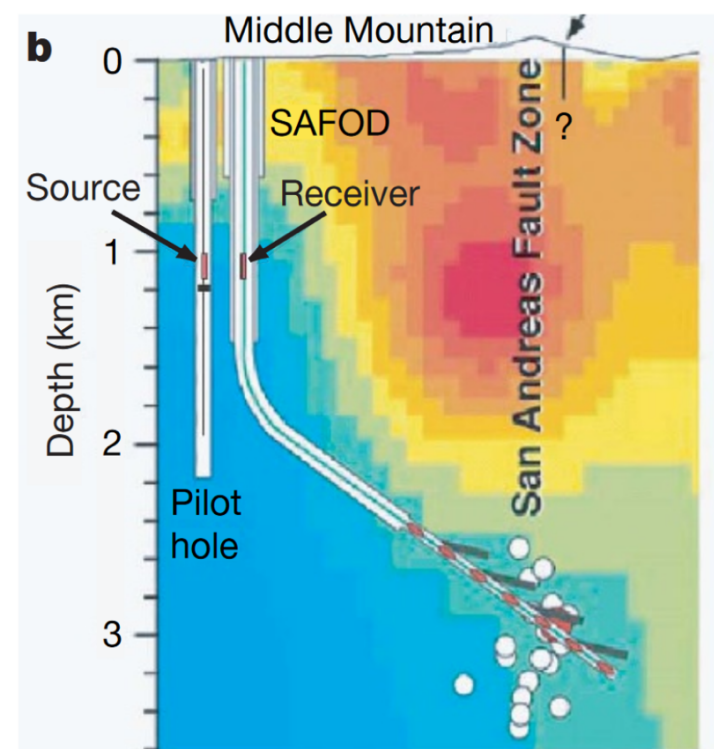


Observations:

Seismicity, dynamic stressing can induce transient changes in:

- permeability — aquifer water level changes
- elastic modulus — decrease wave velocity

Cross-bore active monitoring

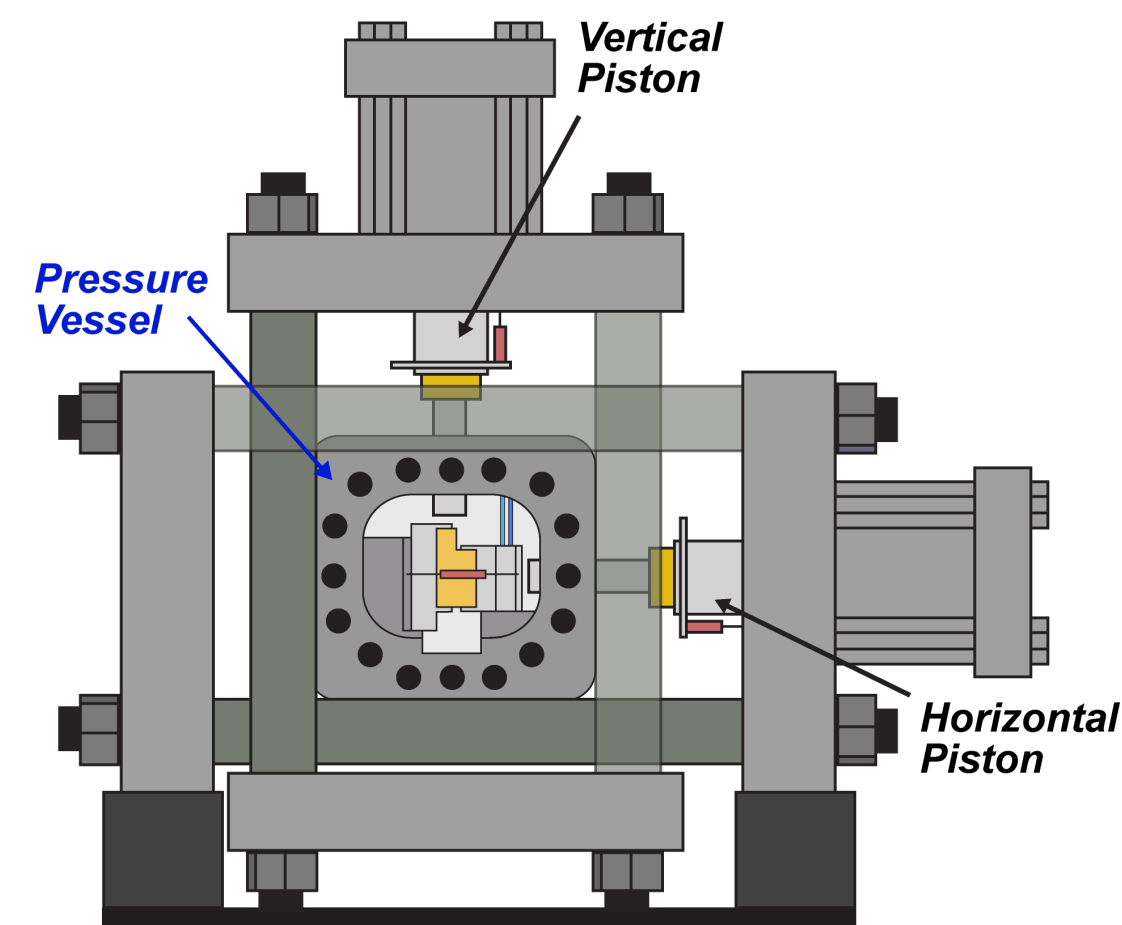


Some implications:

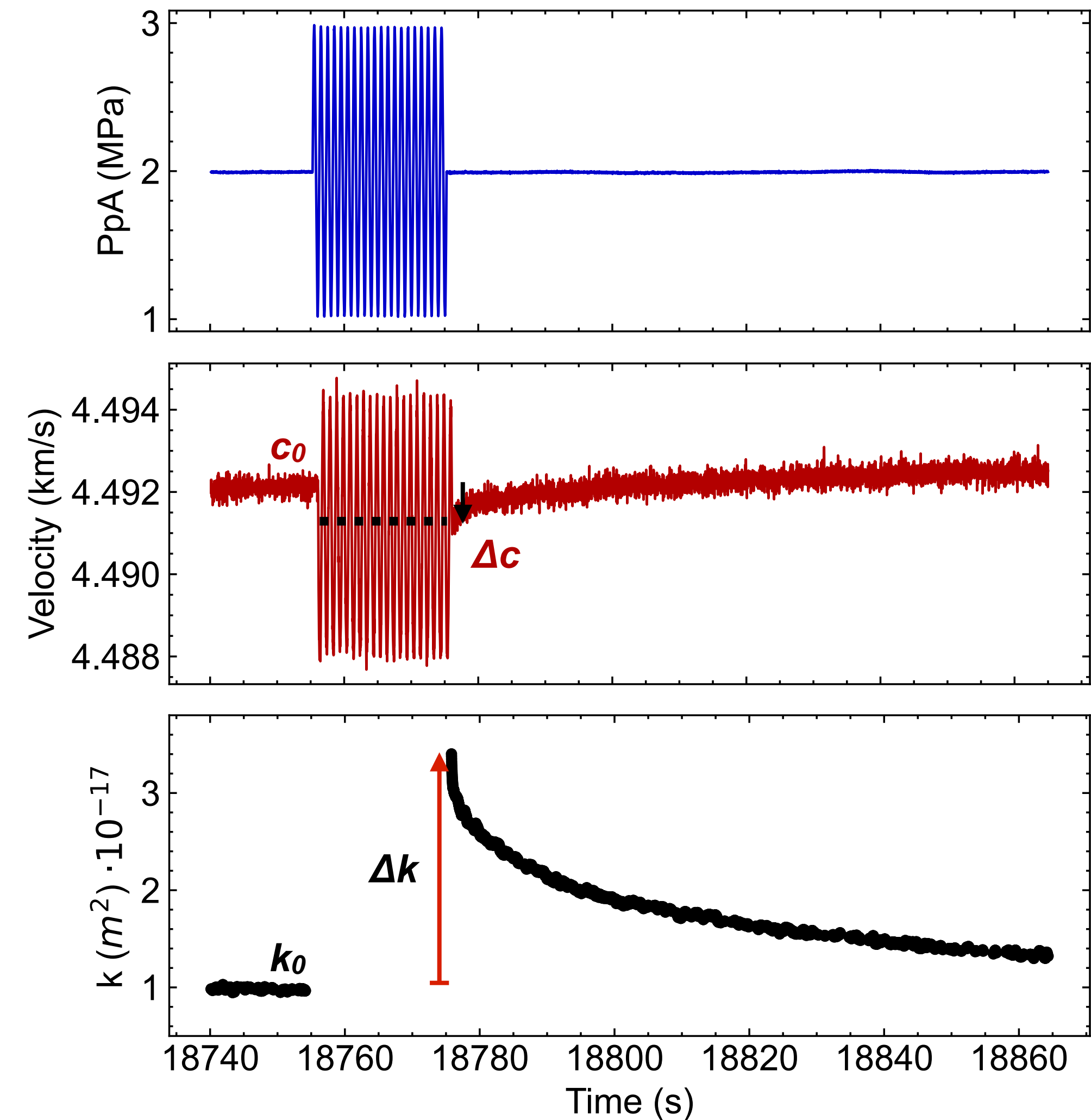
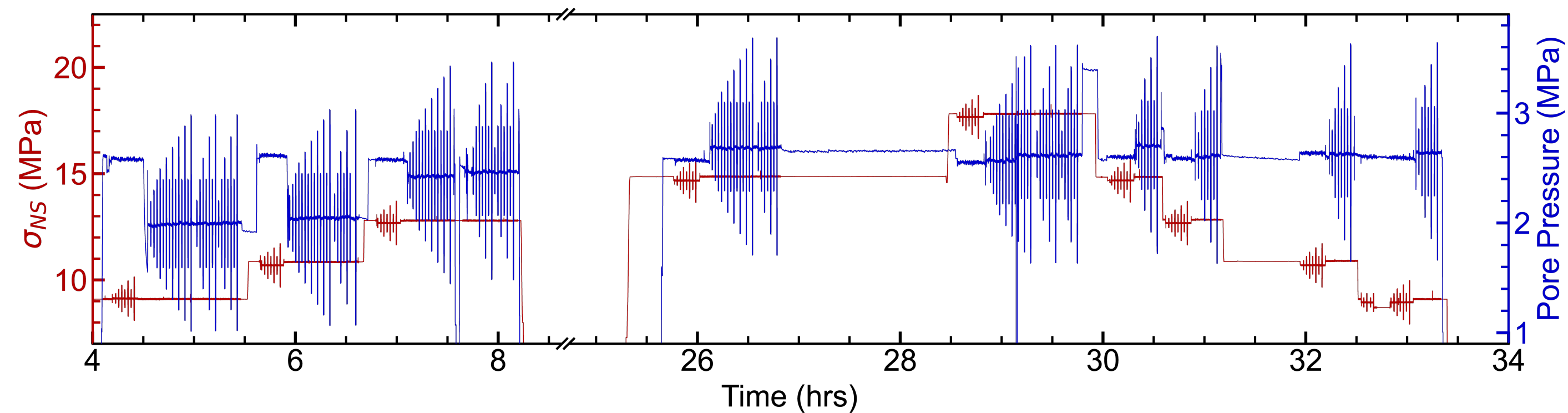
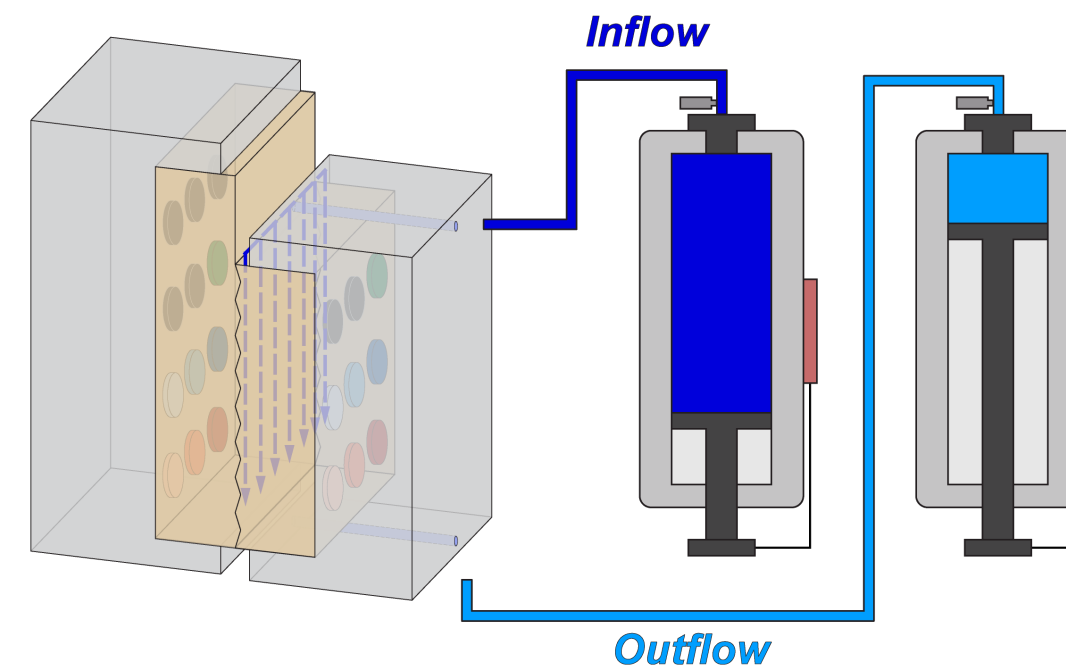
- fault reactivation
- reservoir seal integrity

Simulating field conditions in triaxial lab experiments

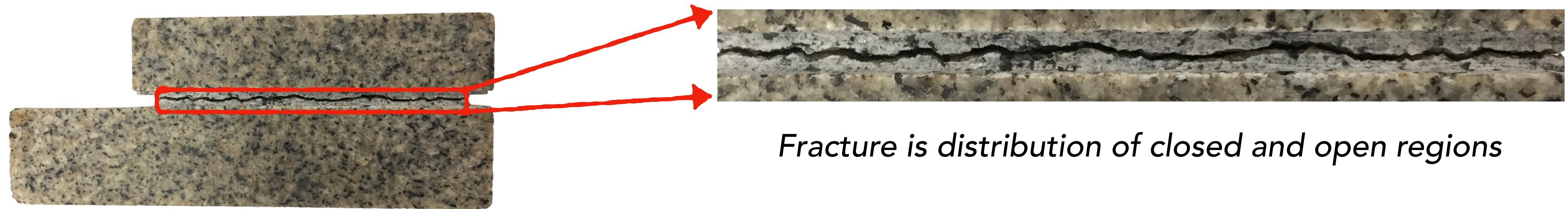
Biaxial Deformation Apparatus



**Concurrent measurements of active
p-wave & fluid transport monitoring**

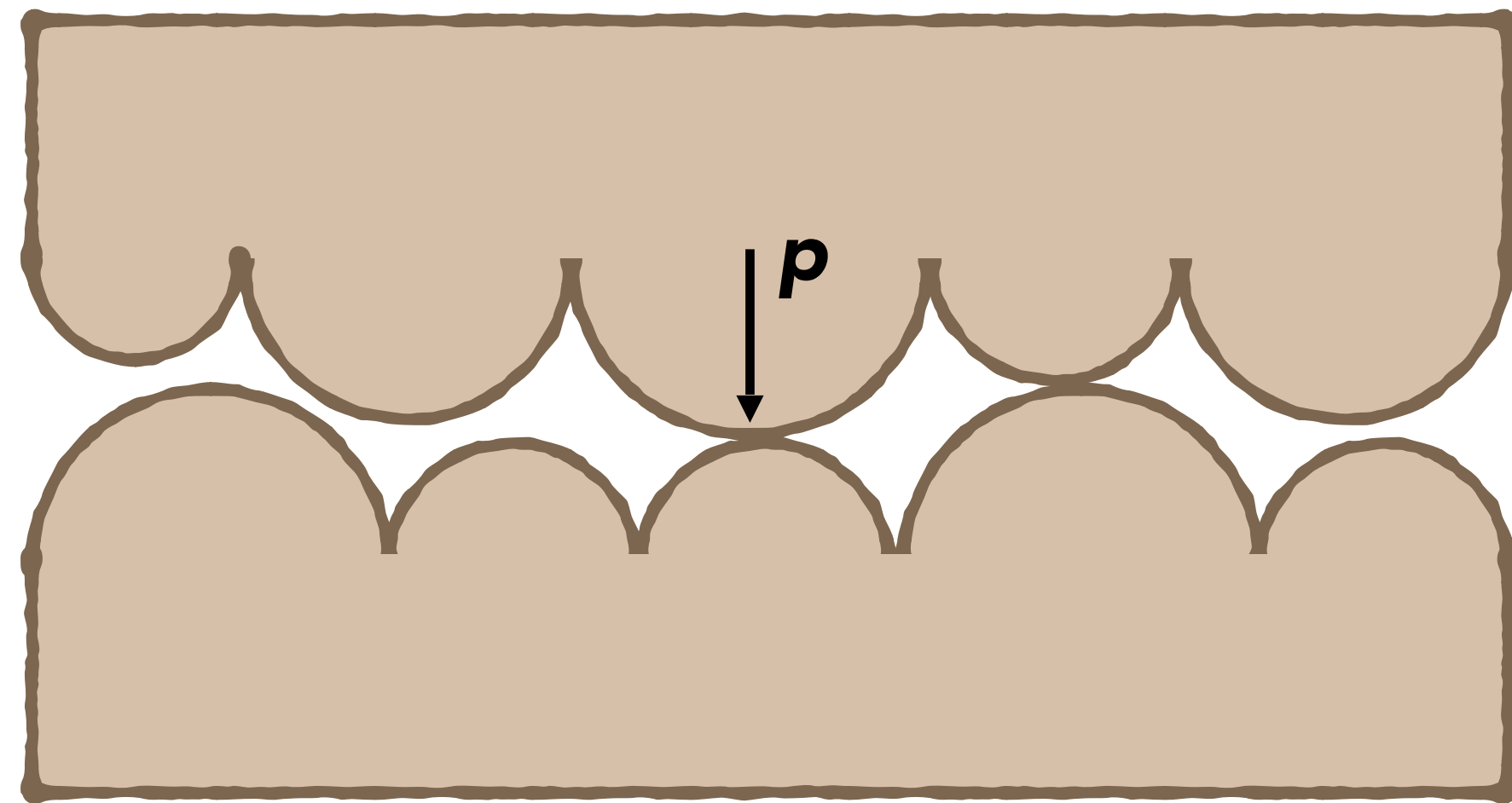


Poromechanics are dominated by small-scale properties



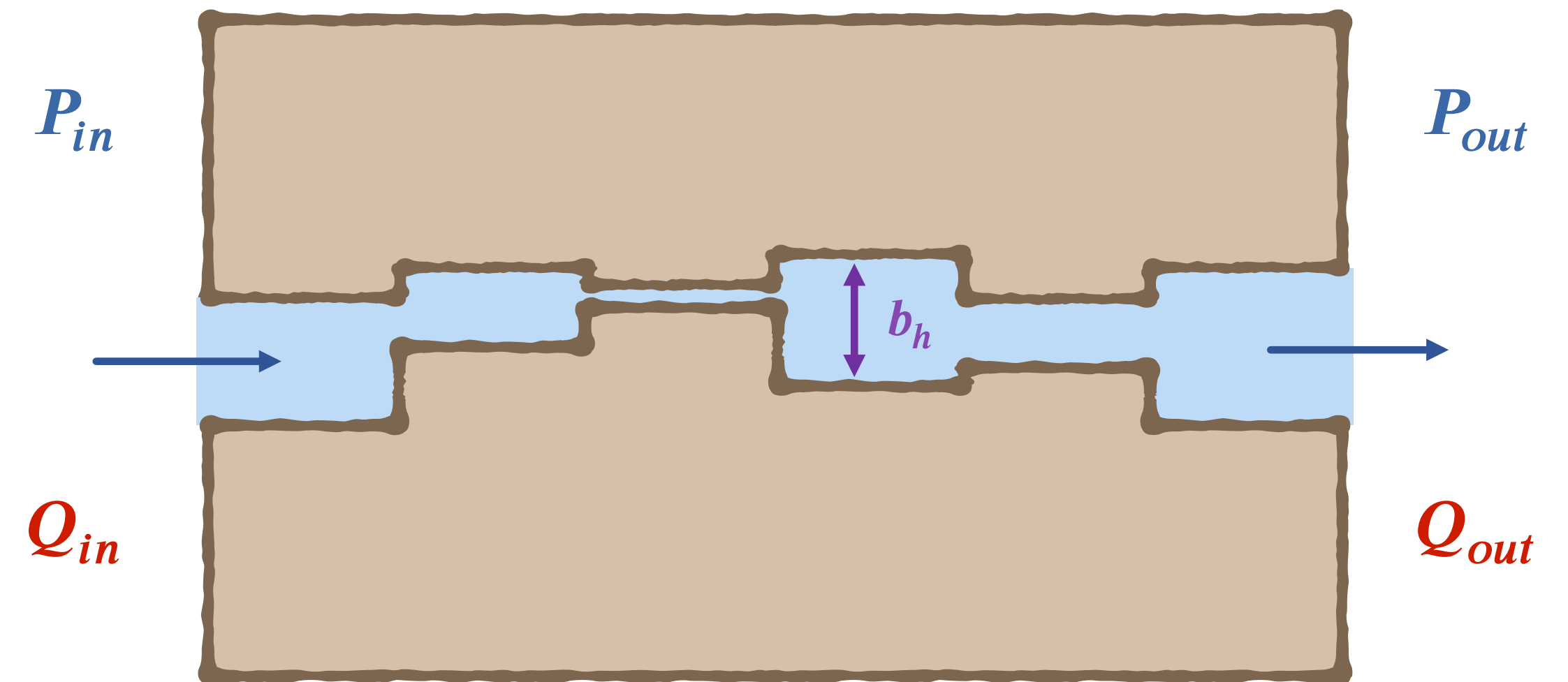
Fracture is distribution of closed and open regions

Deformation is controlled by contact area & stiffness



Think: many springs with different stiffness

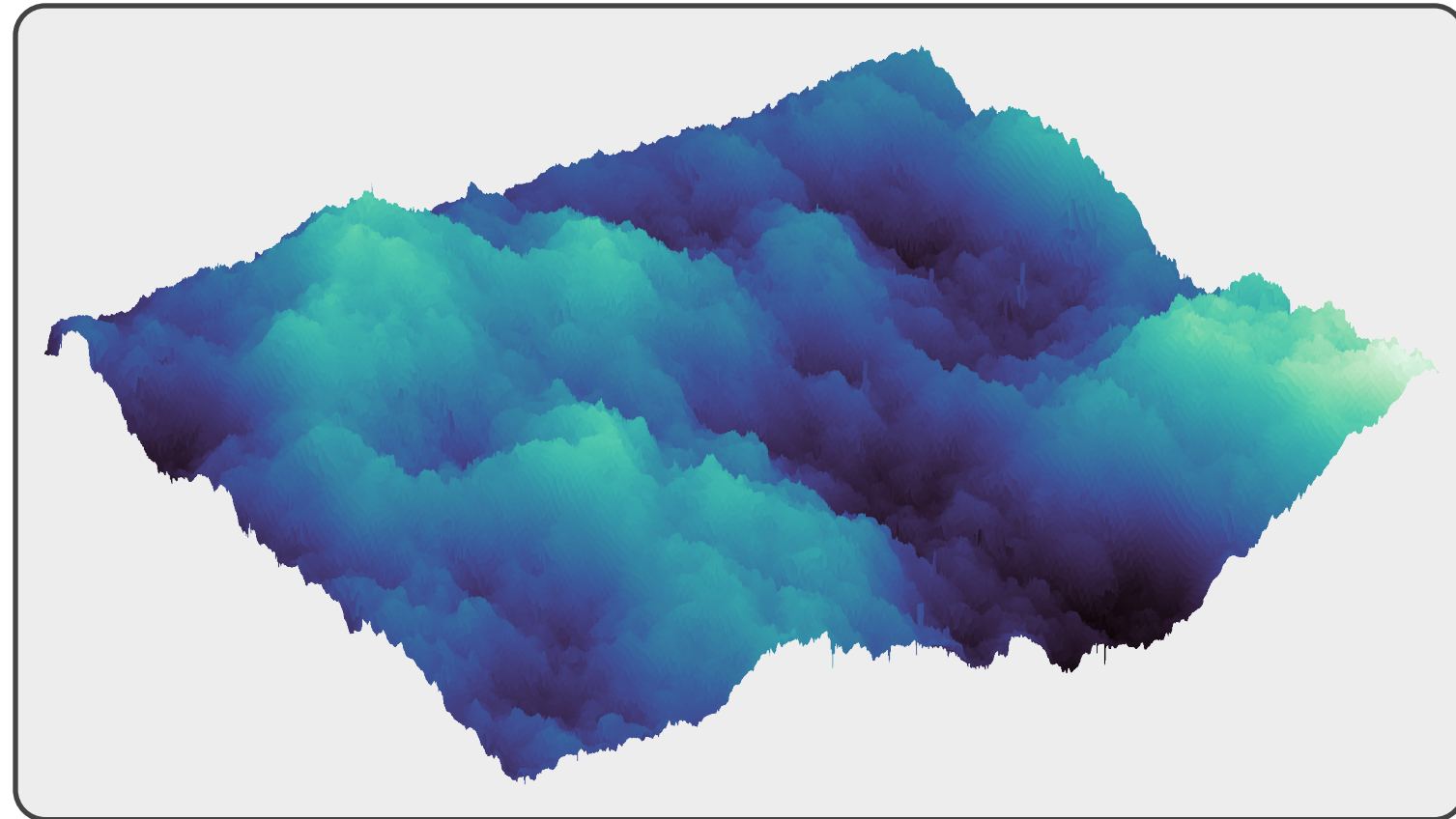
Fluid flow is controlled by gap heights, b_h



$$b_h^3 \propto \frac{\Delta Q}{\Delta P} \propto k$$

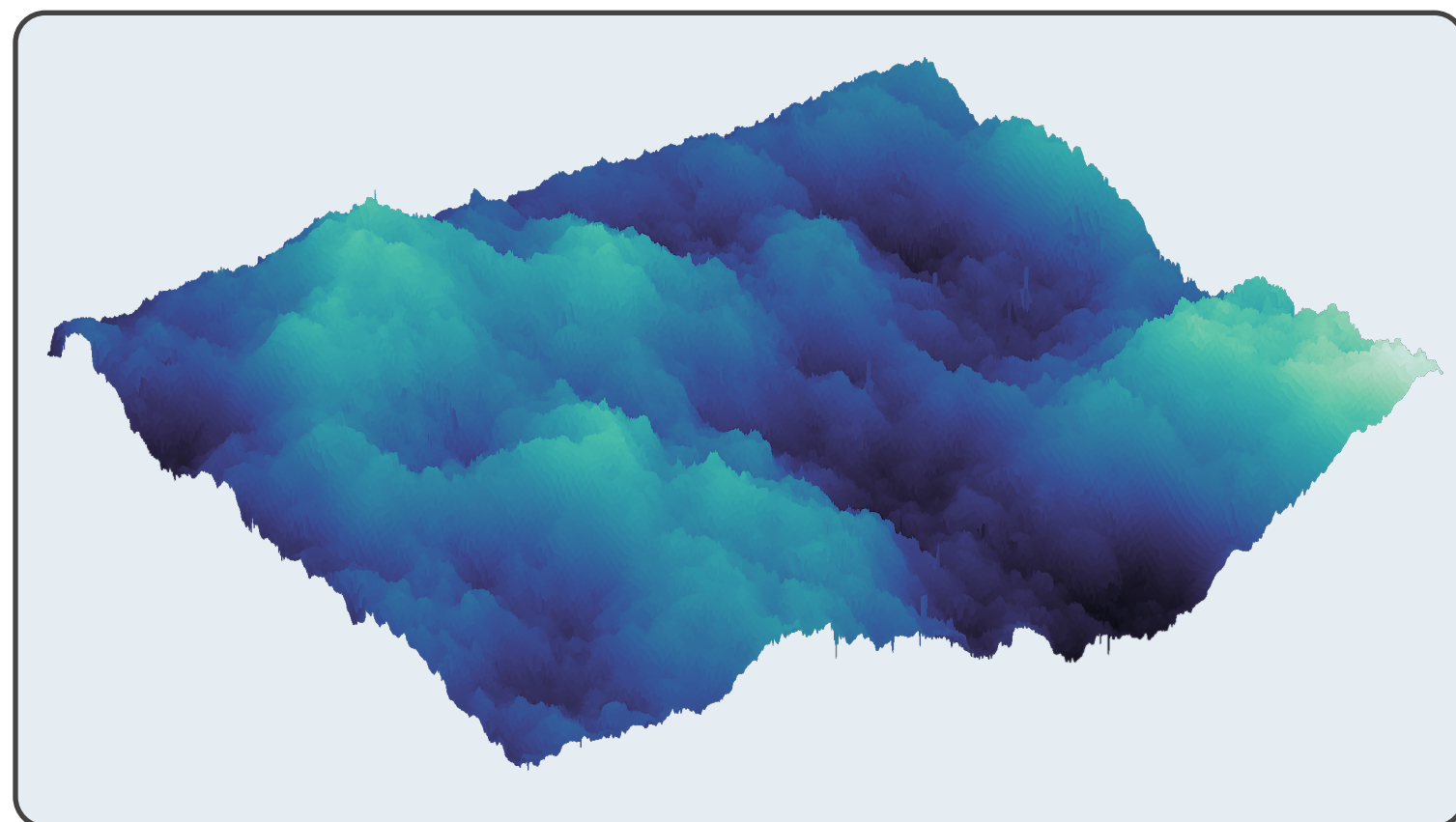
Constructing a composite aperture from surface profilometry

Top Surface



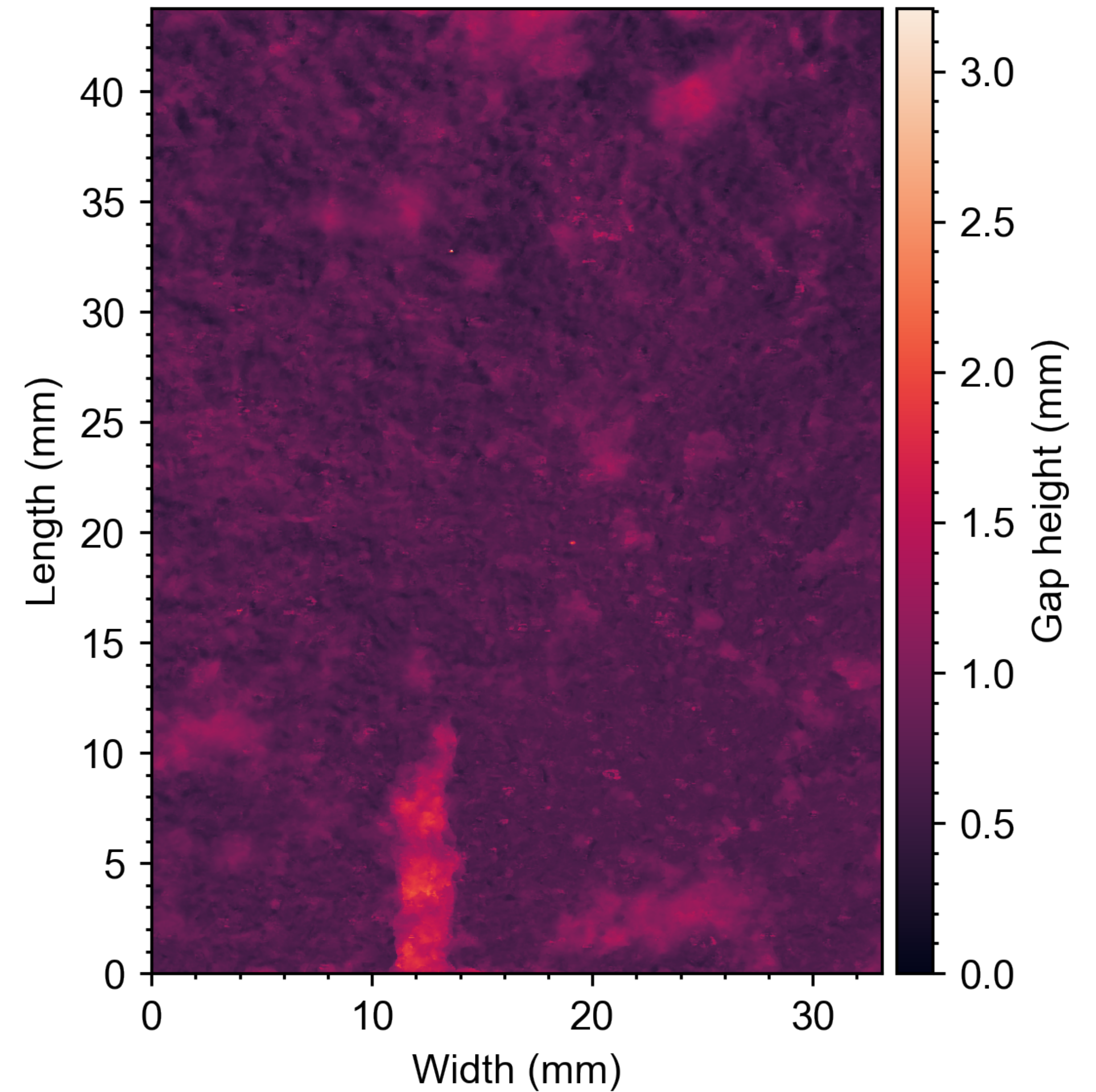
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Bottom Surface



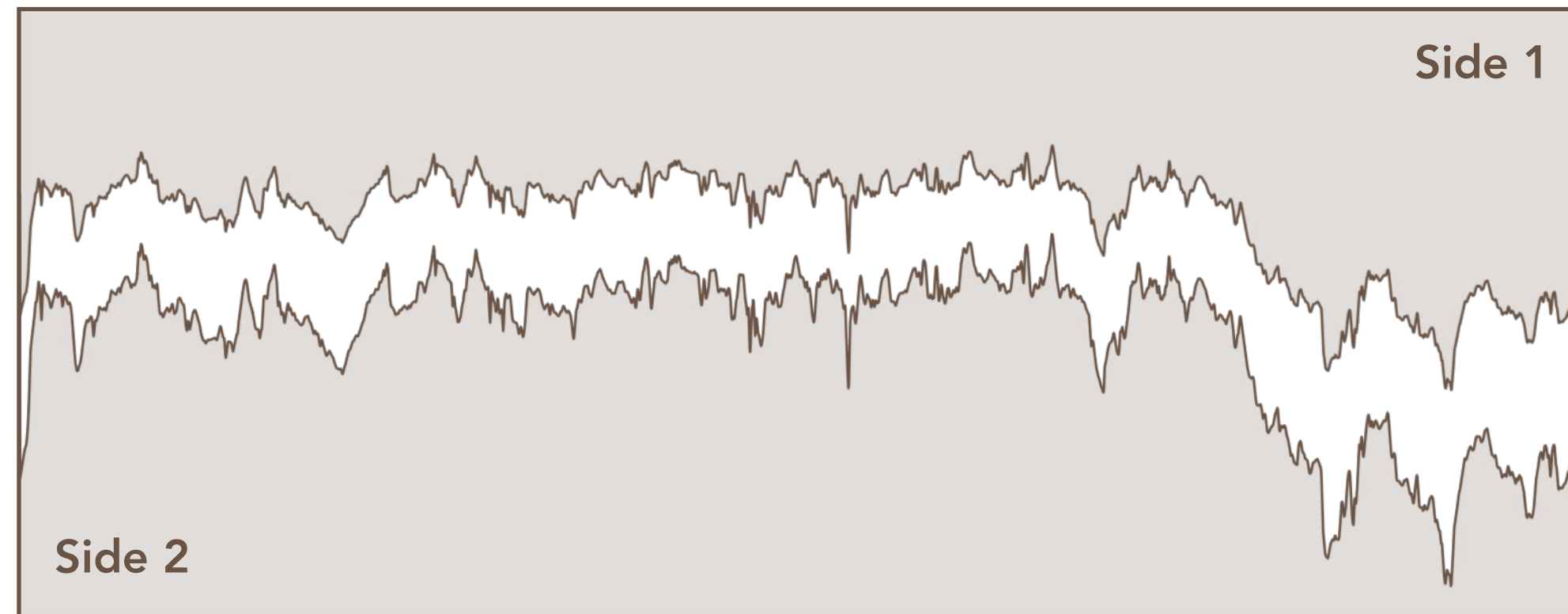
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Fracture Aperture: Gap Heights



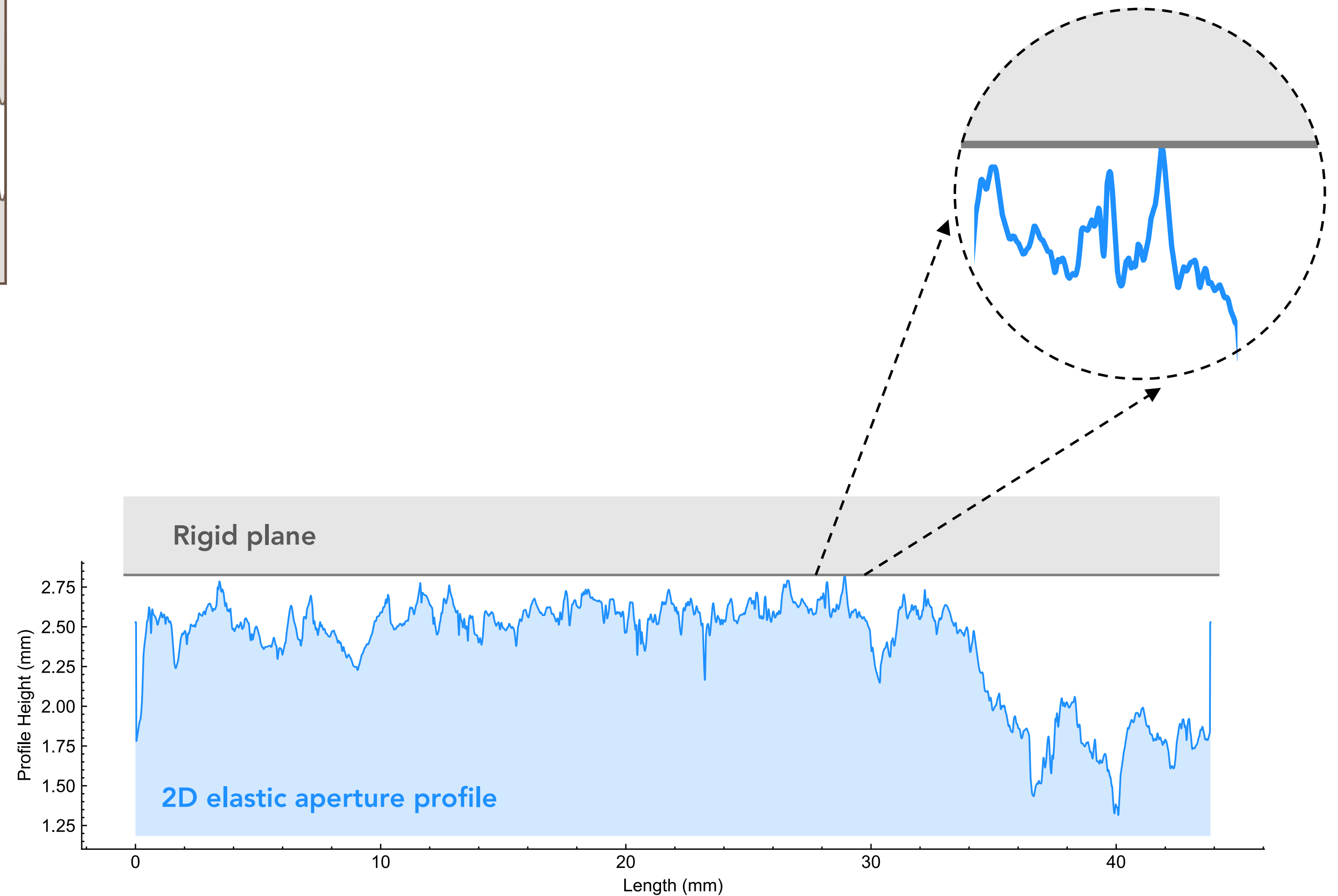
Stress-displacement relation – Hertzian contact distribution

Fracture



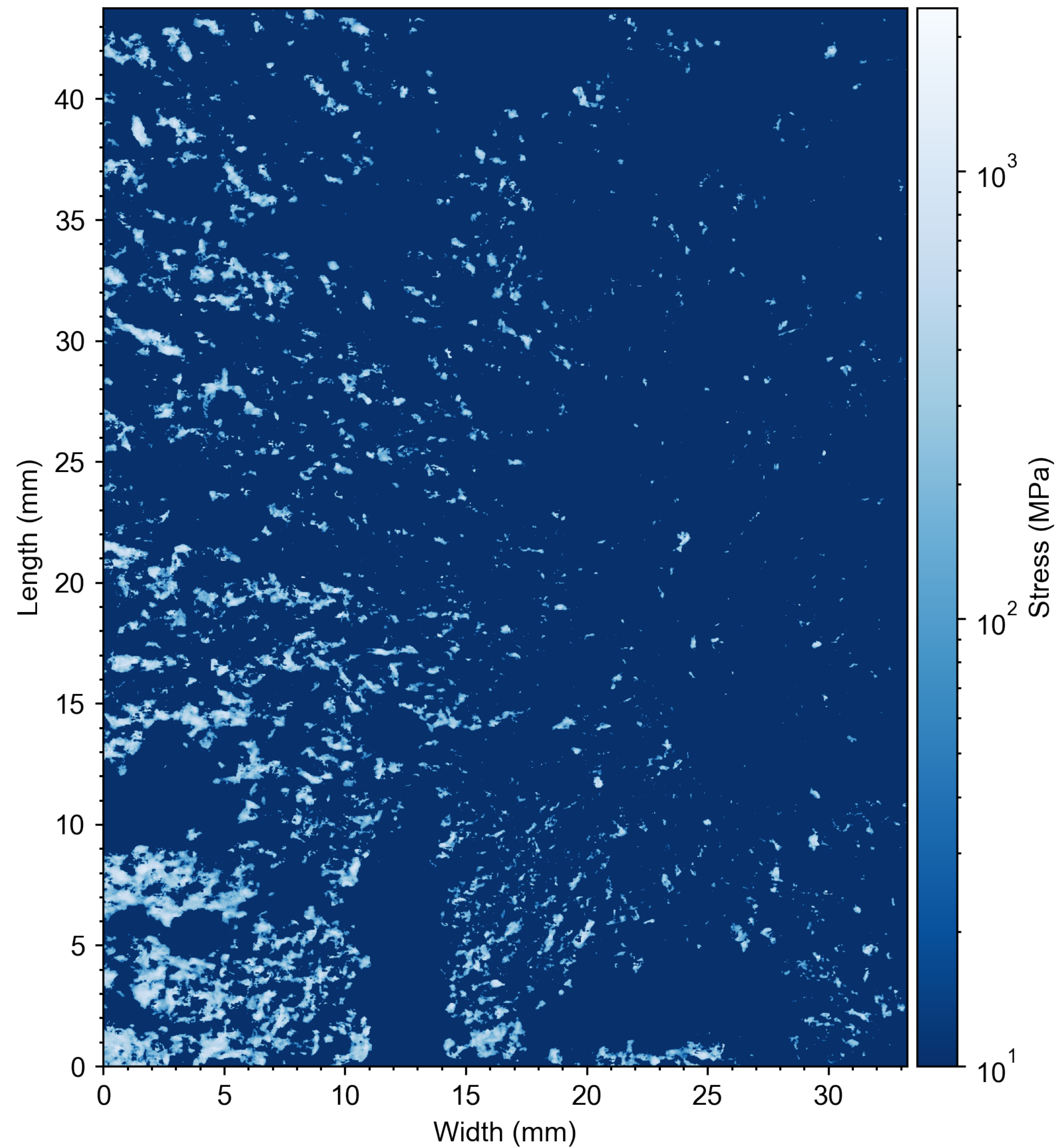
Equivalent problem:

Rigid plane in contact with elastic composite aperture.

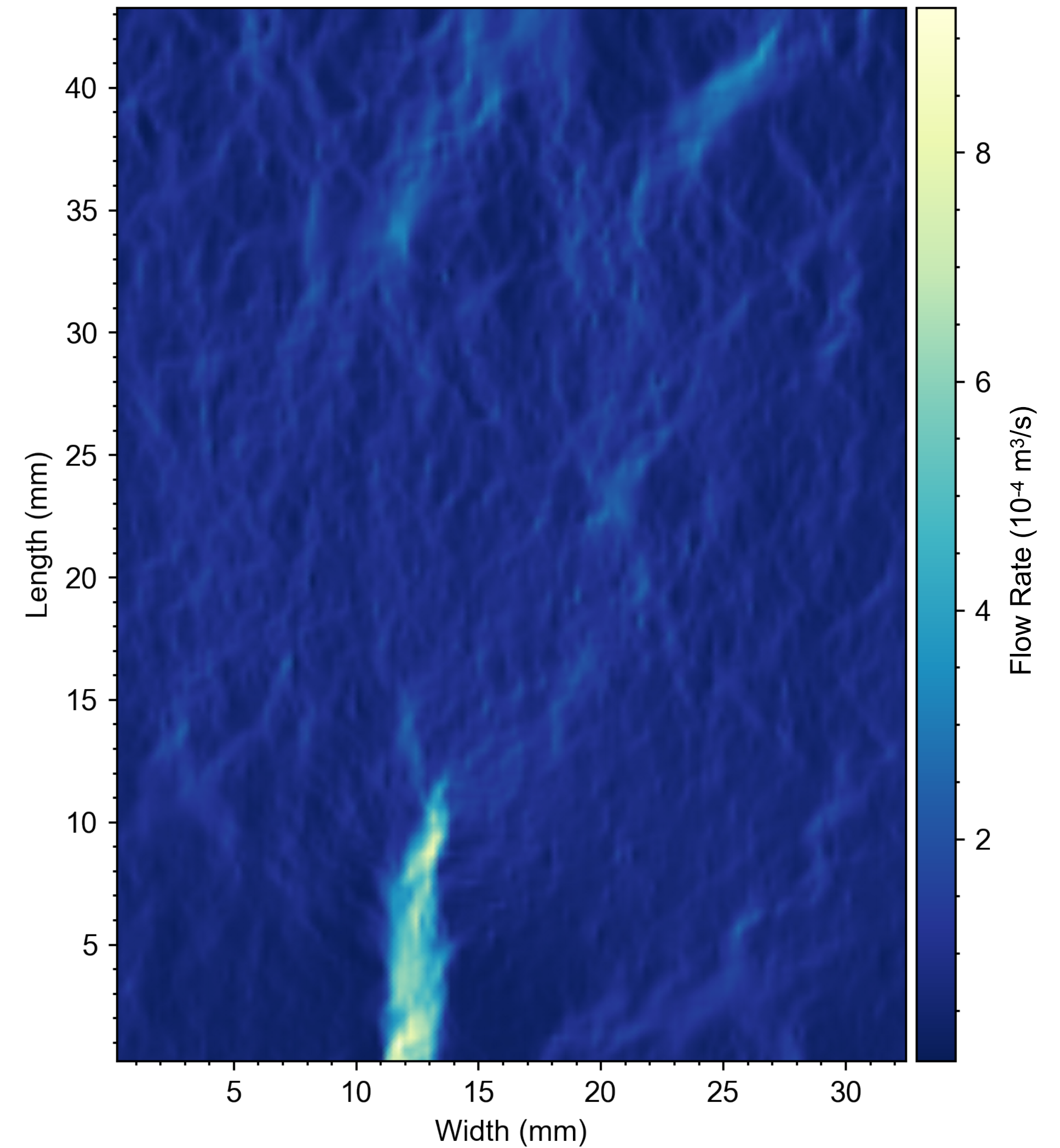


Stresses on asperities near/beyond breaking strength

20 MPa Applied Stress

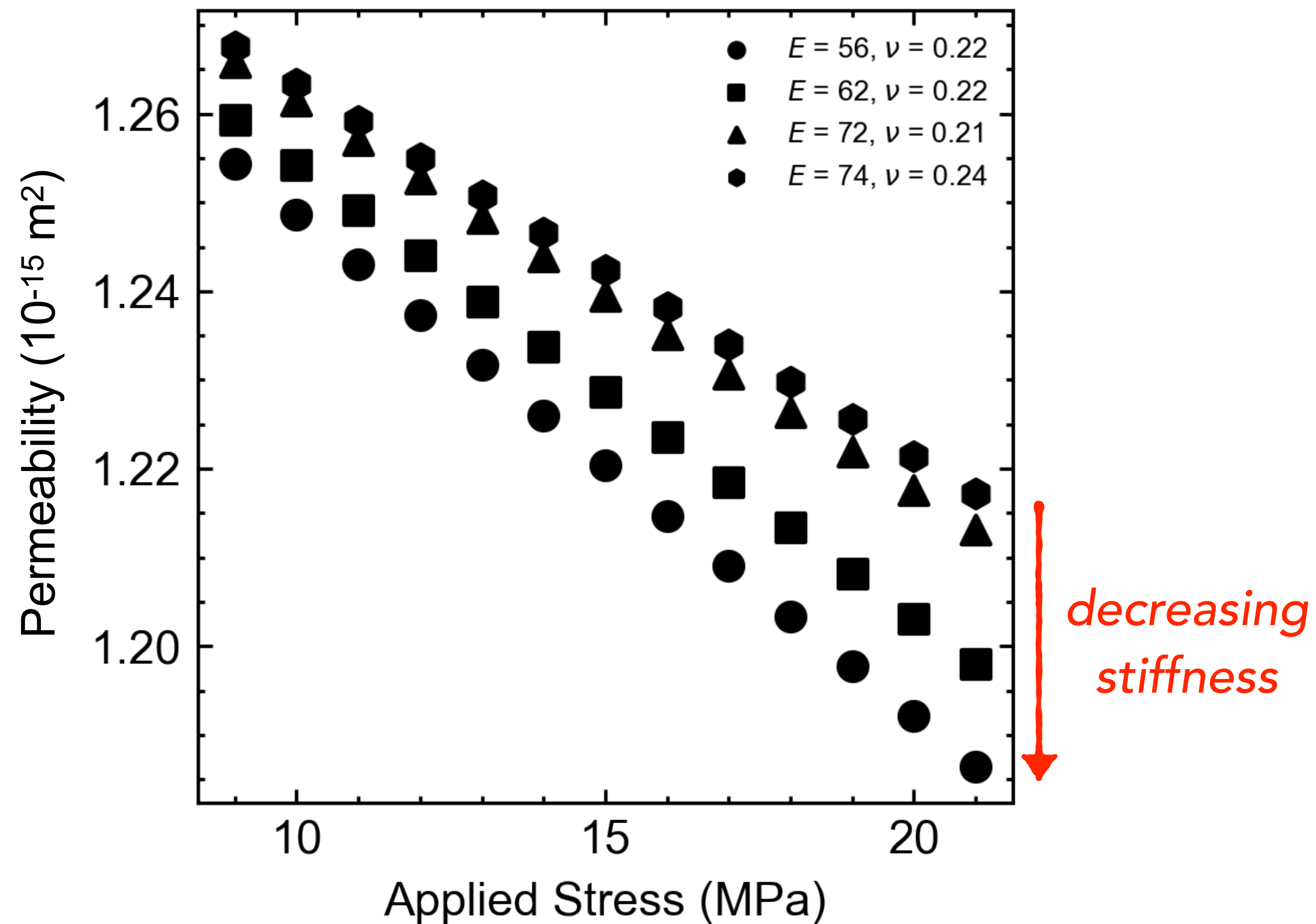


20 MPa Applied Stress; $\Delta P = 1.2$ MPa

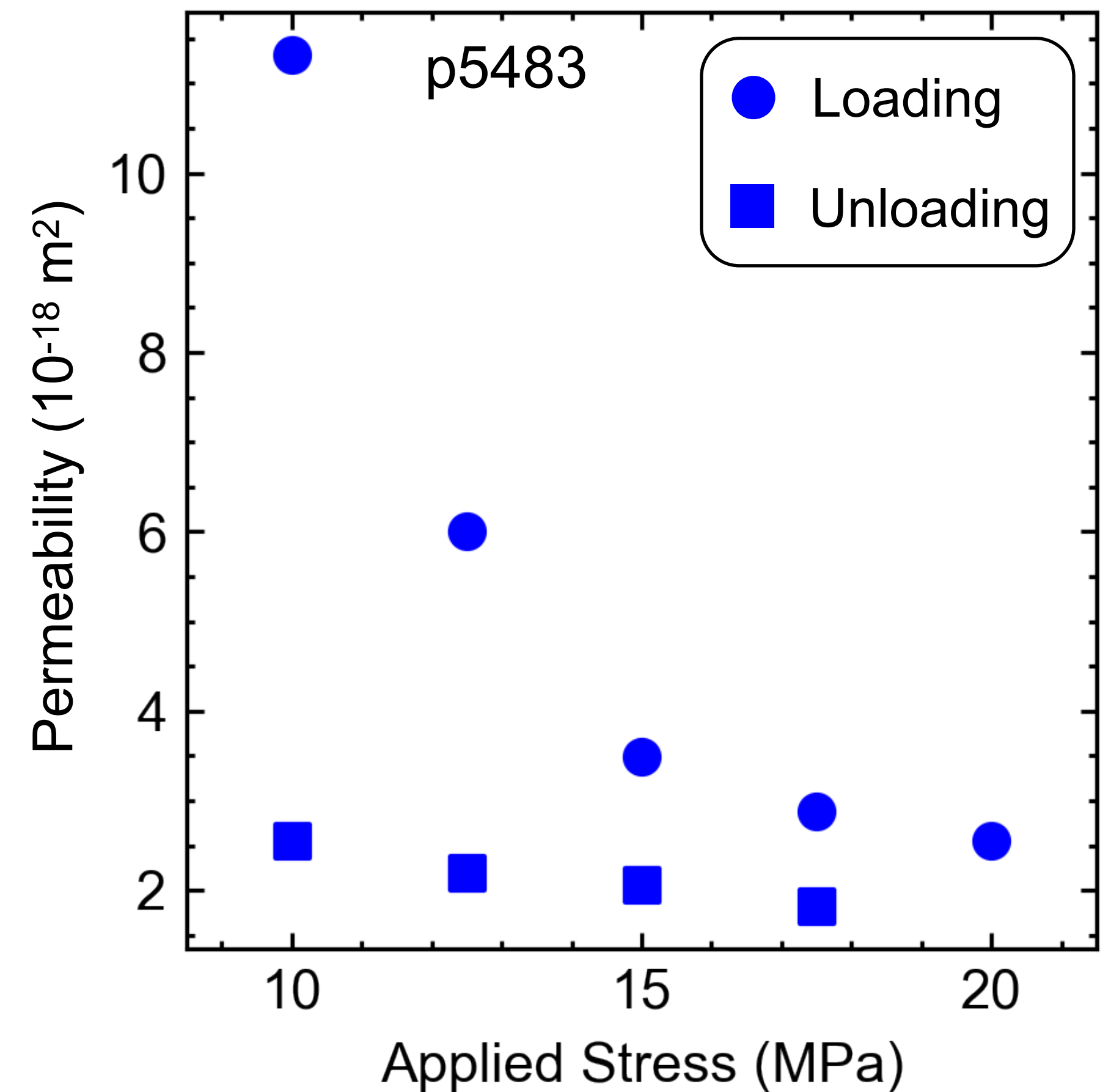


Permeability decreases with applied stress & elastic modulus

Numerical Results

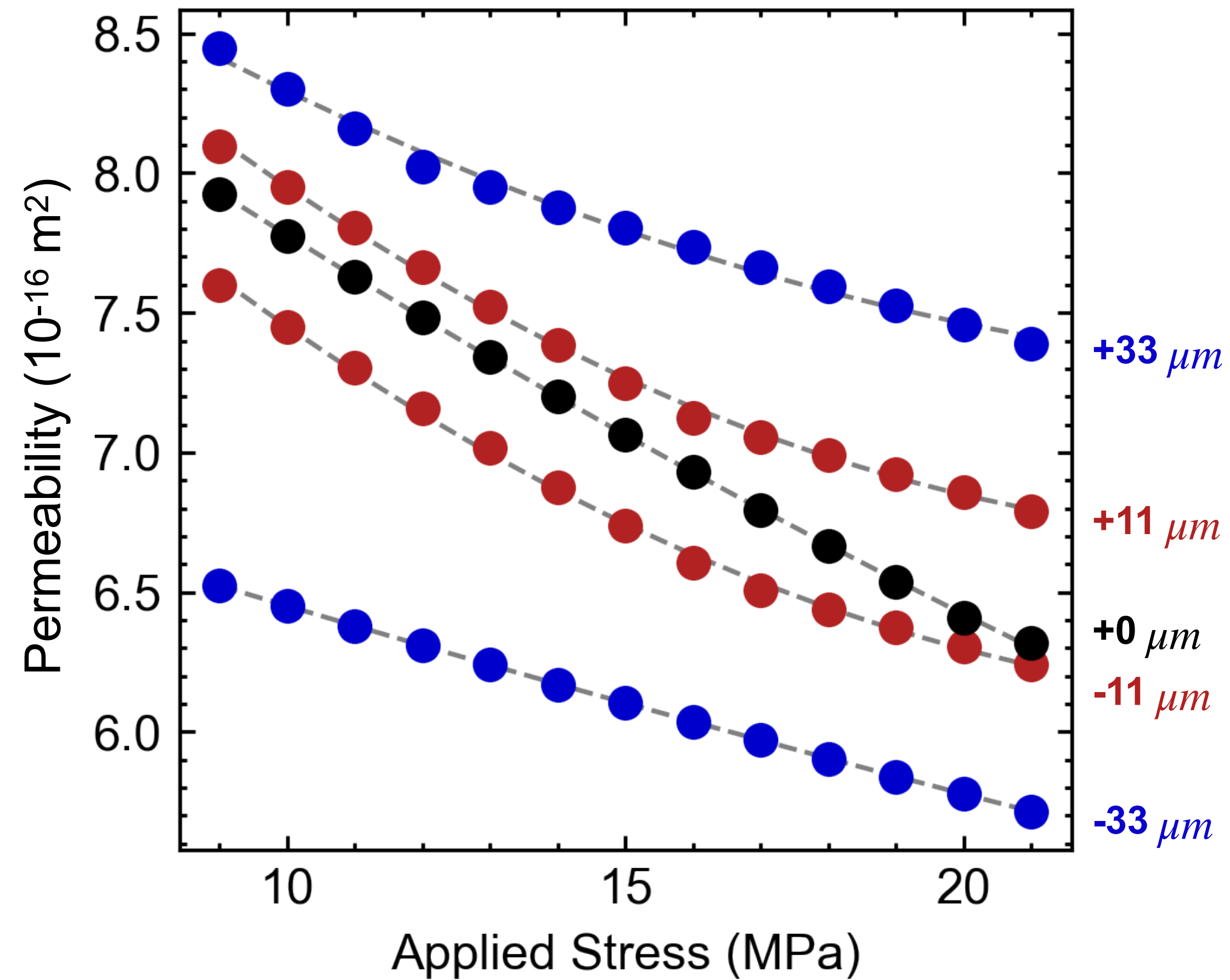


Experimental Results

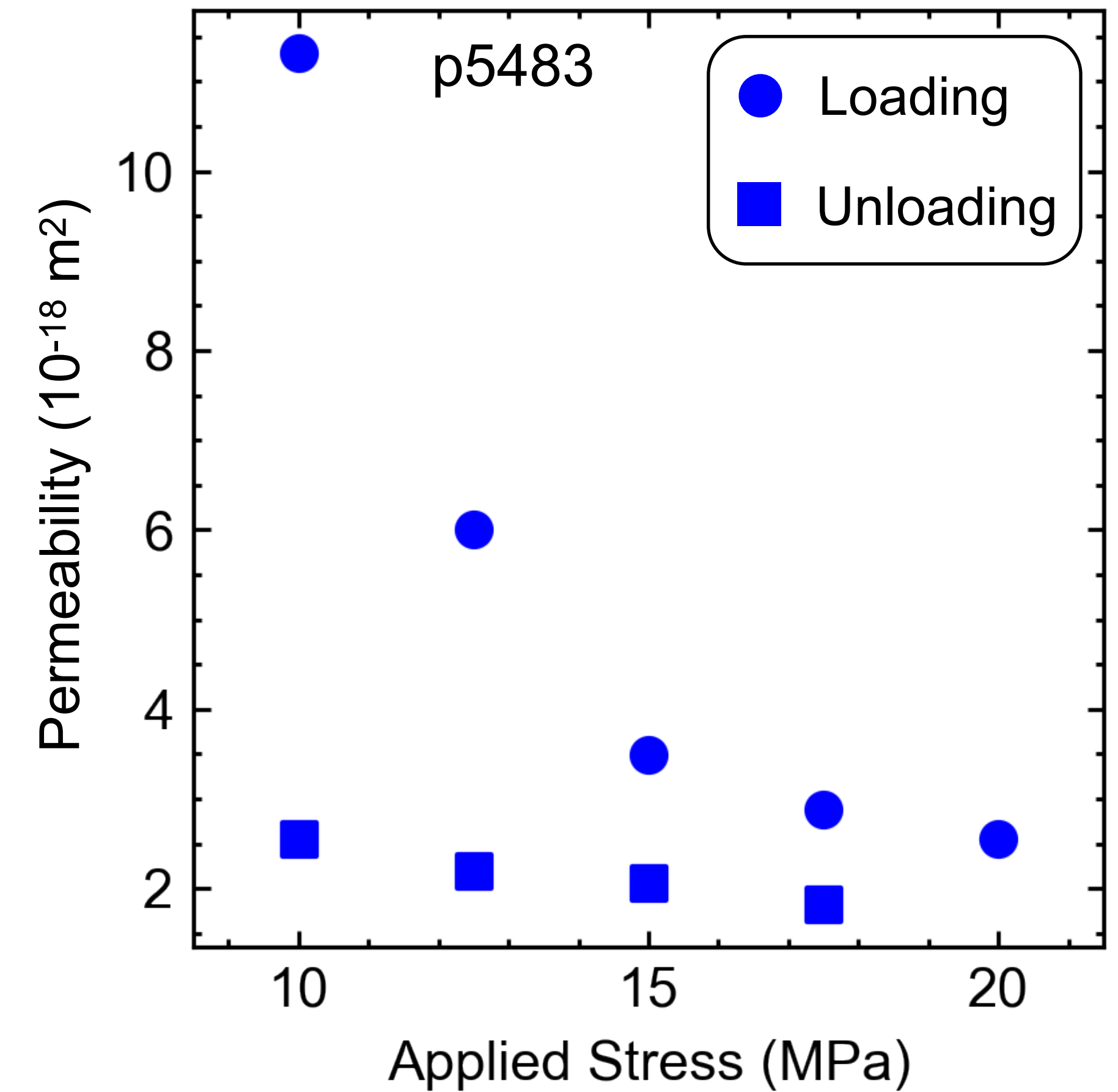


*Fracture surface mating may change during loading:
nonlinear permeability change*

Numerical Results

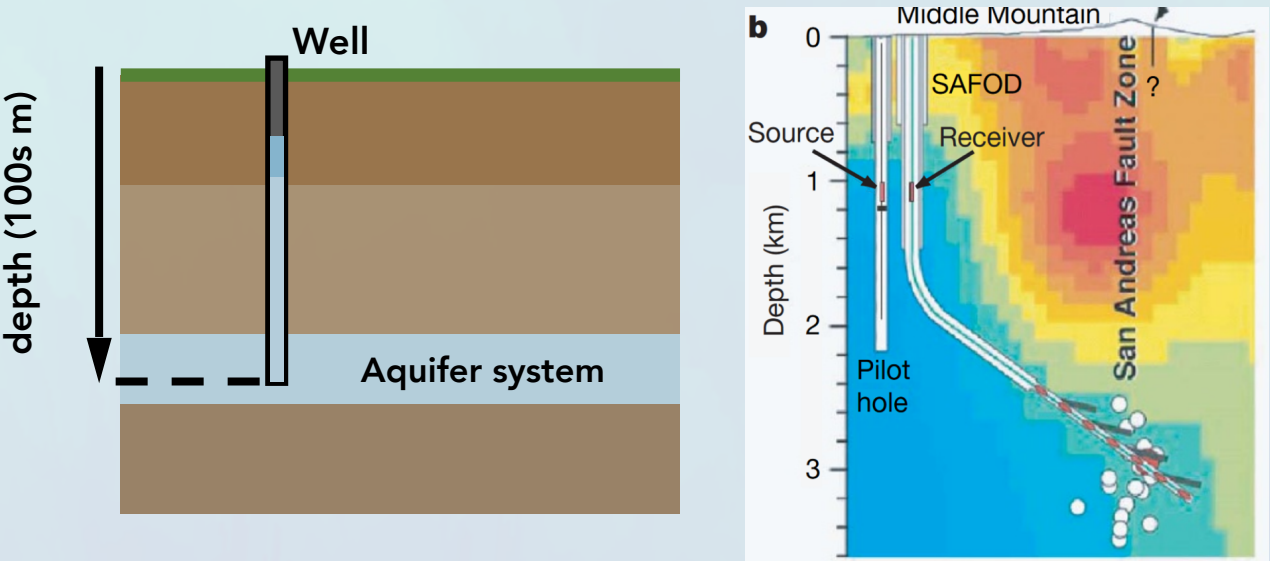


Experimental Results

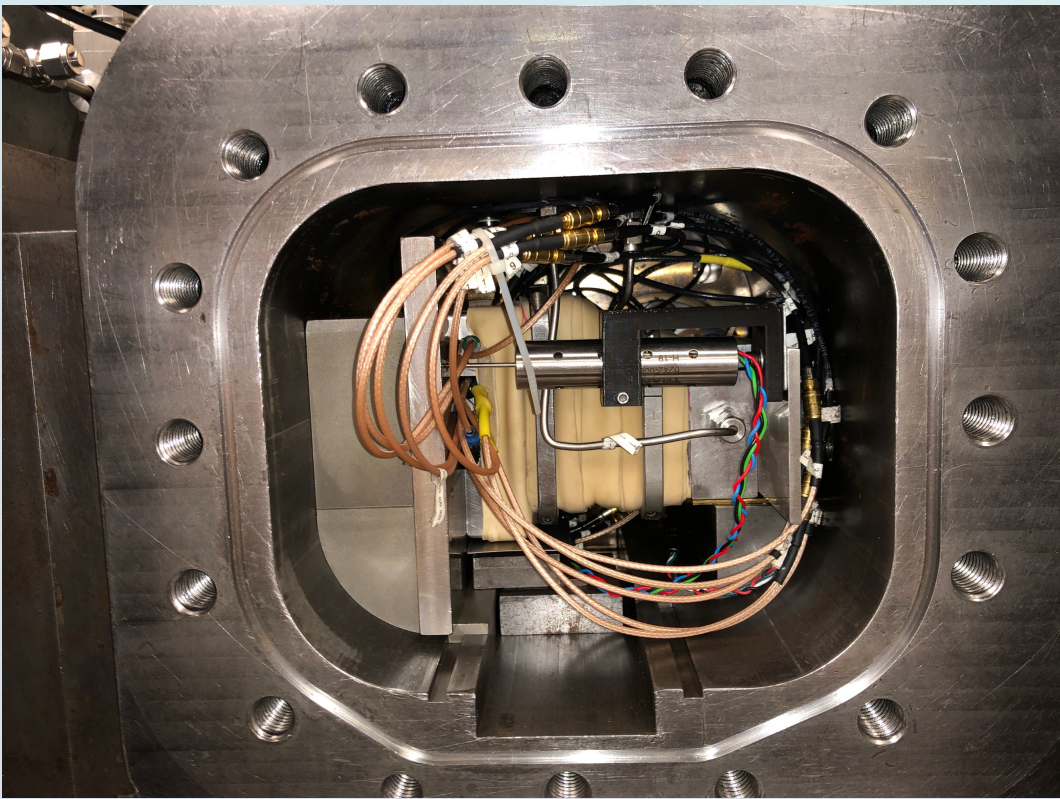


Summary

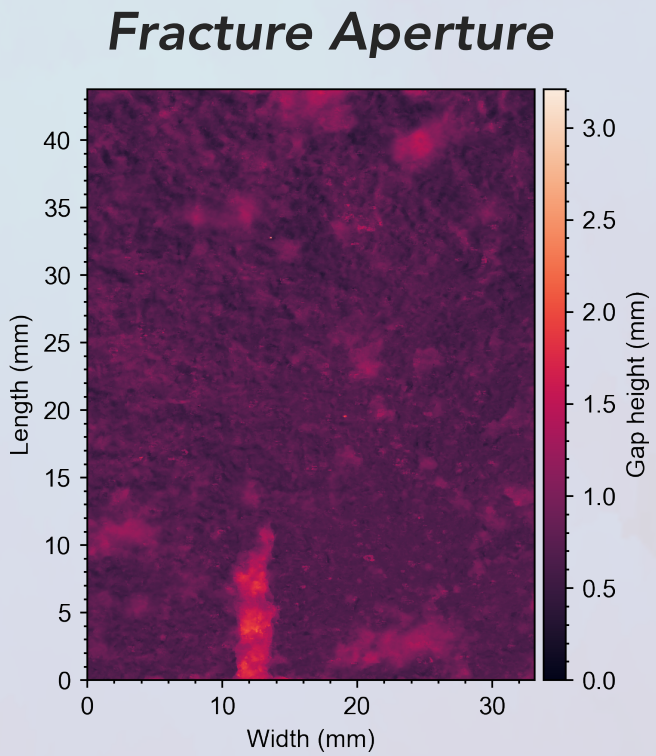
Stress perturbations cause transient softening & permeability change



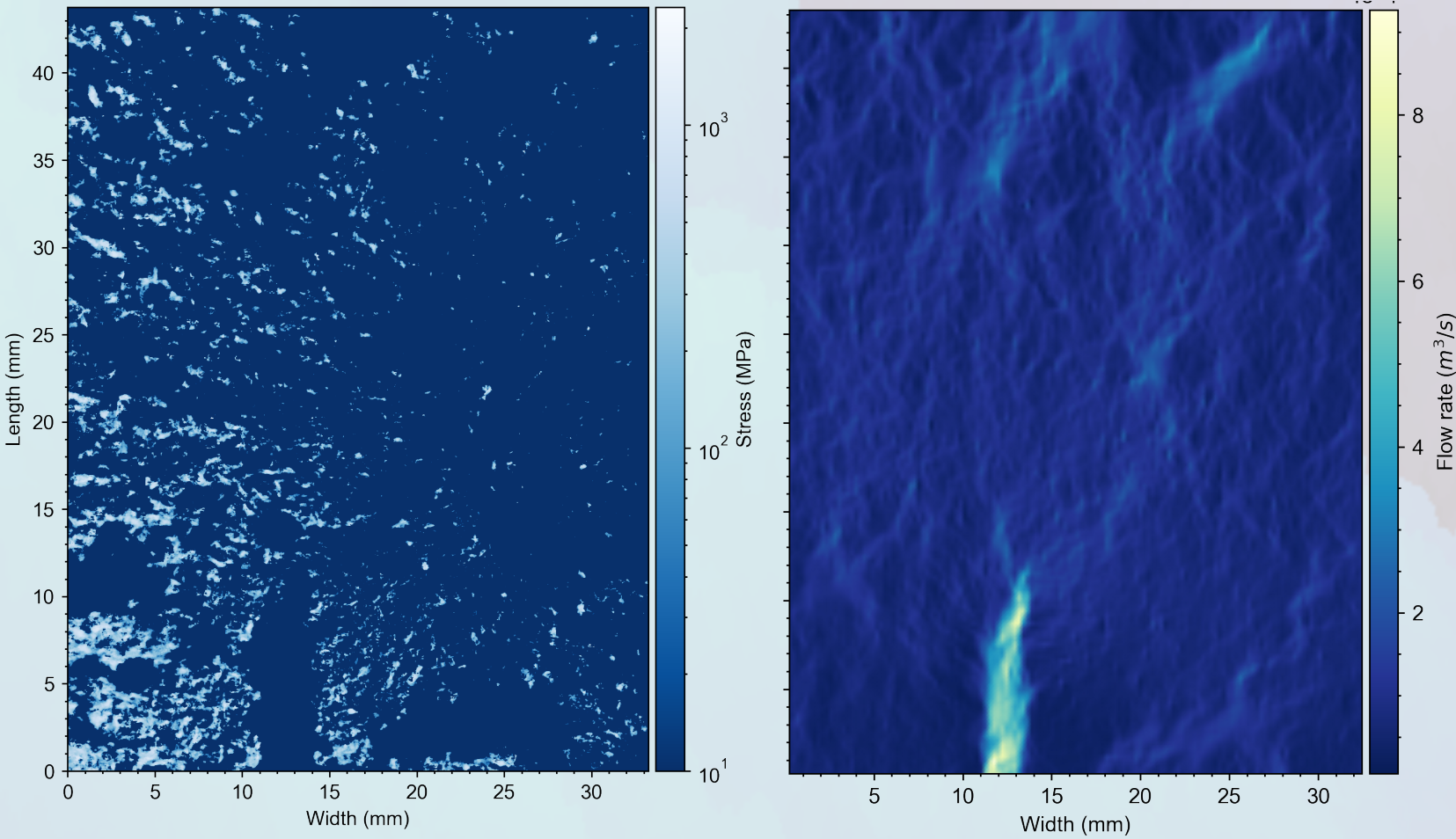
Simulate field conditions using unique, well-controlled laboratory experiments



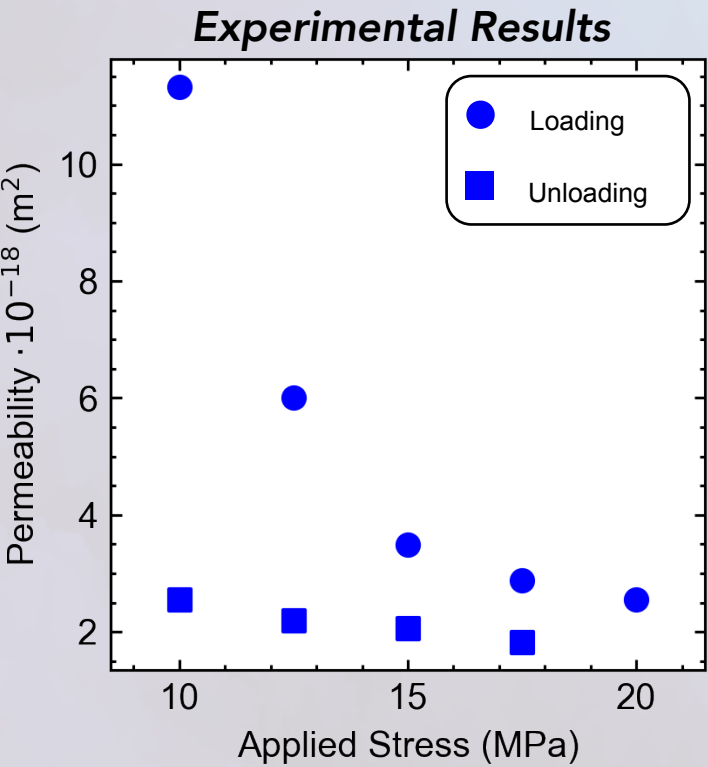
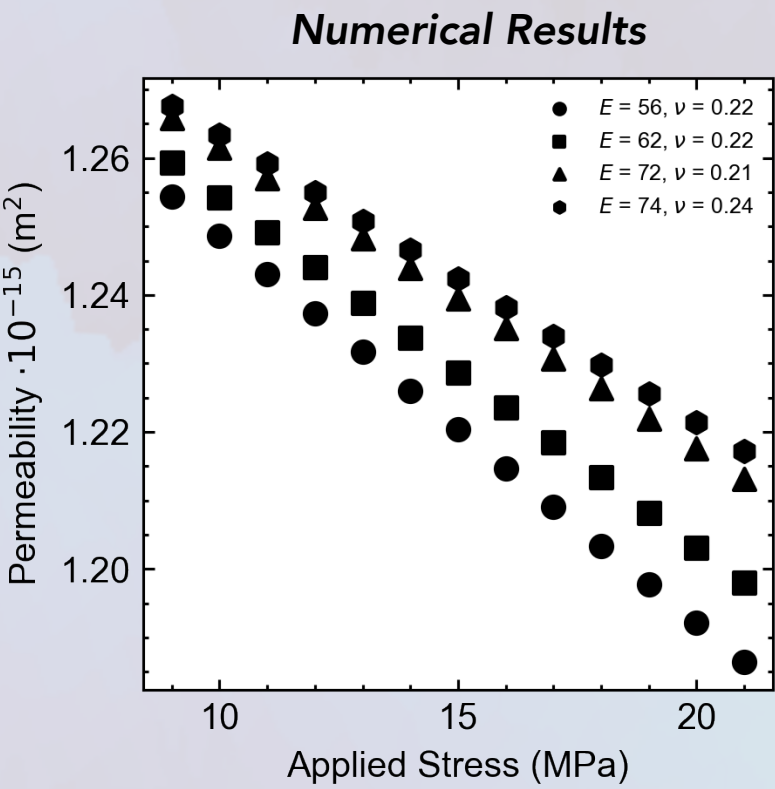
Construct composite aperture from surface profilometry



Simulate asperity deformation and fluid flow



Elastic properties and surface alignment important for capturing complex relationship between asperity deformation and permeability





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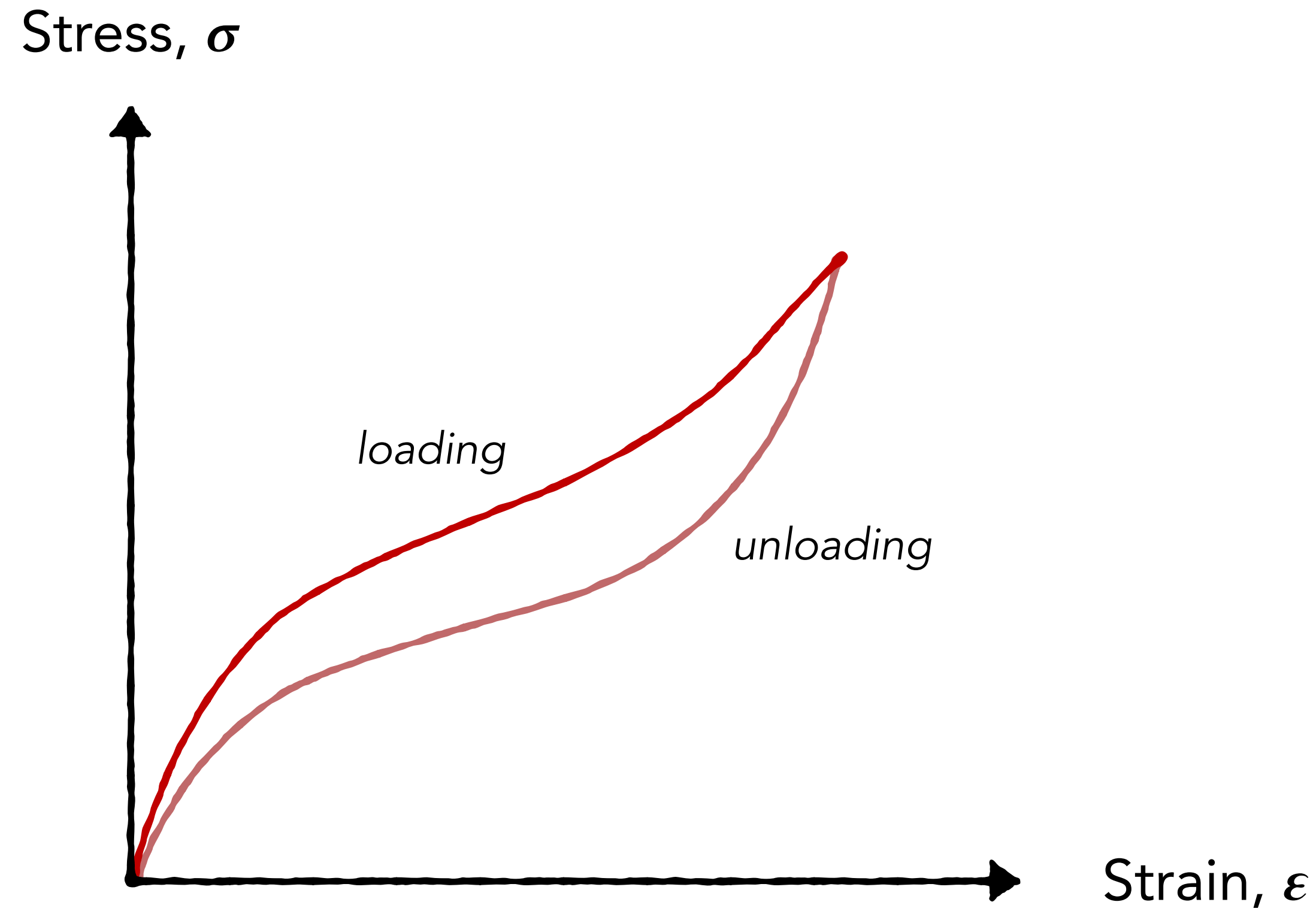
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Nonlinear elasticity describes complex mechanical properties of rocks

Nonlinear elastic deformation -- rocks

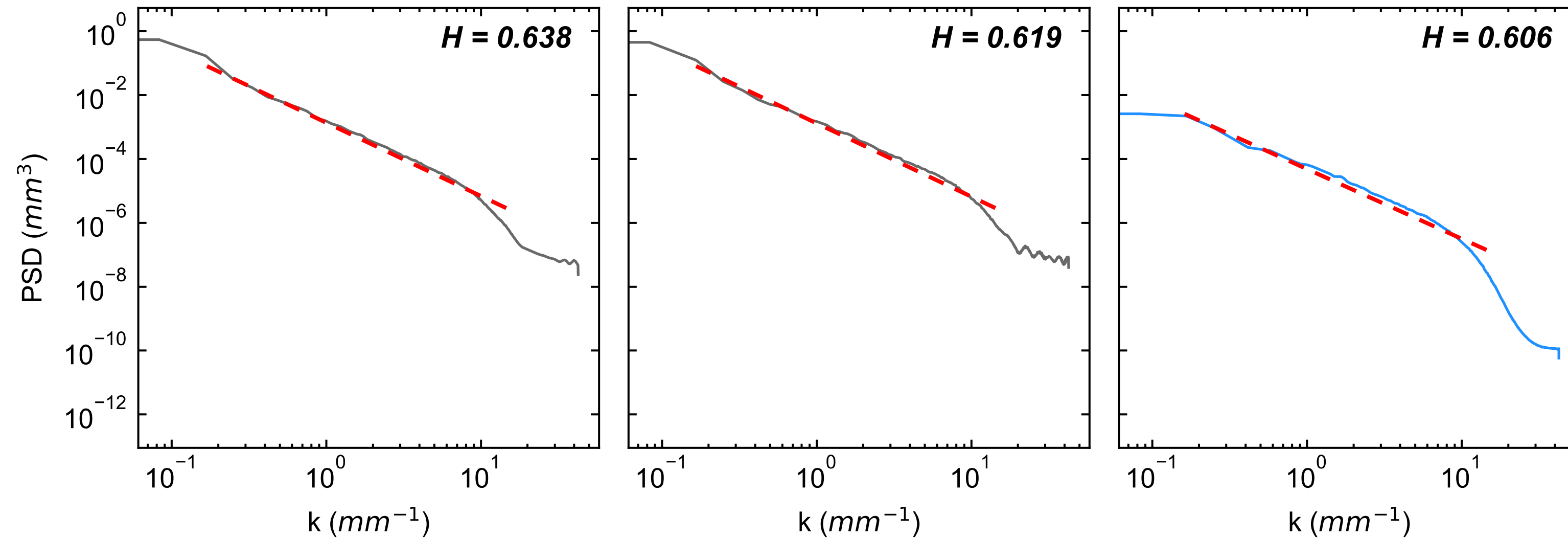


Nonlinear elasticity...

- memory -- hysteresis
- grain boundaries, dislocation, stiffnesses
- occurs in damaged, granular, heterogenous materials



Fracture shows self-affine roughness – implications for scale-invariance



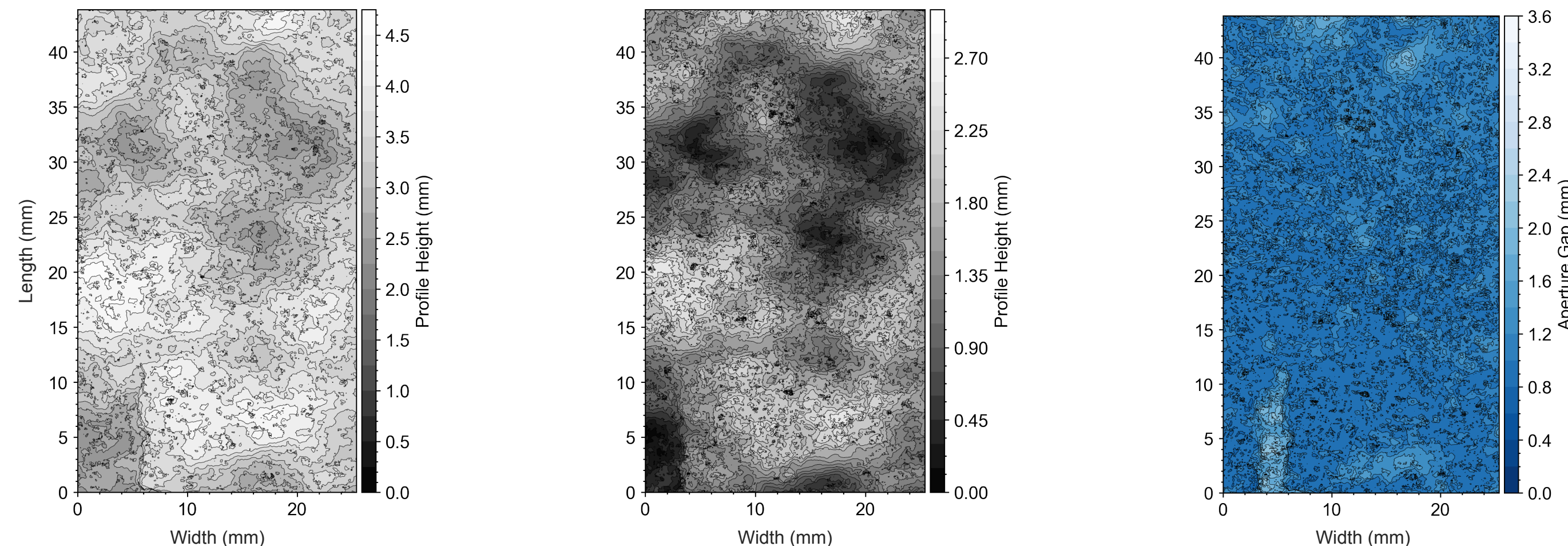
Roughness in spectral domain:

Spectral content of surface roughness (faults, fractured rock, etc.) tells us about relevant asperity scales

Hurst exponent:

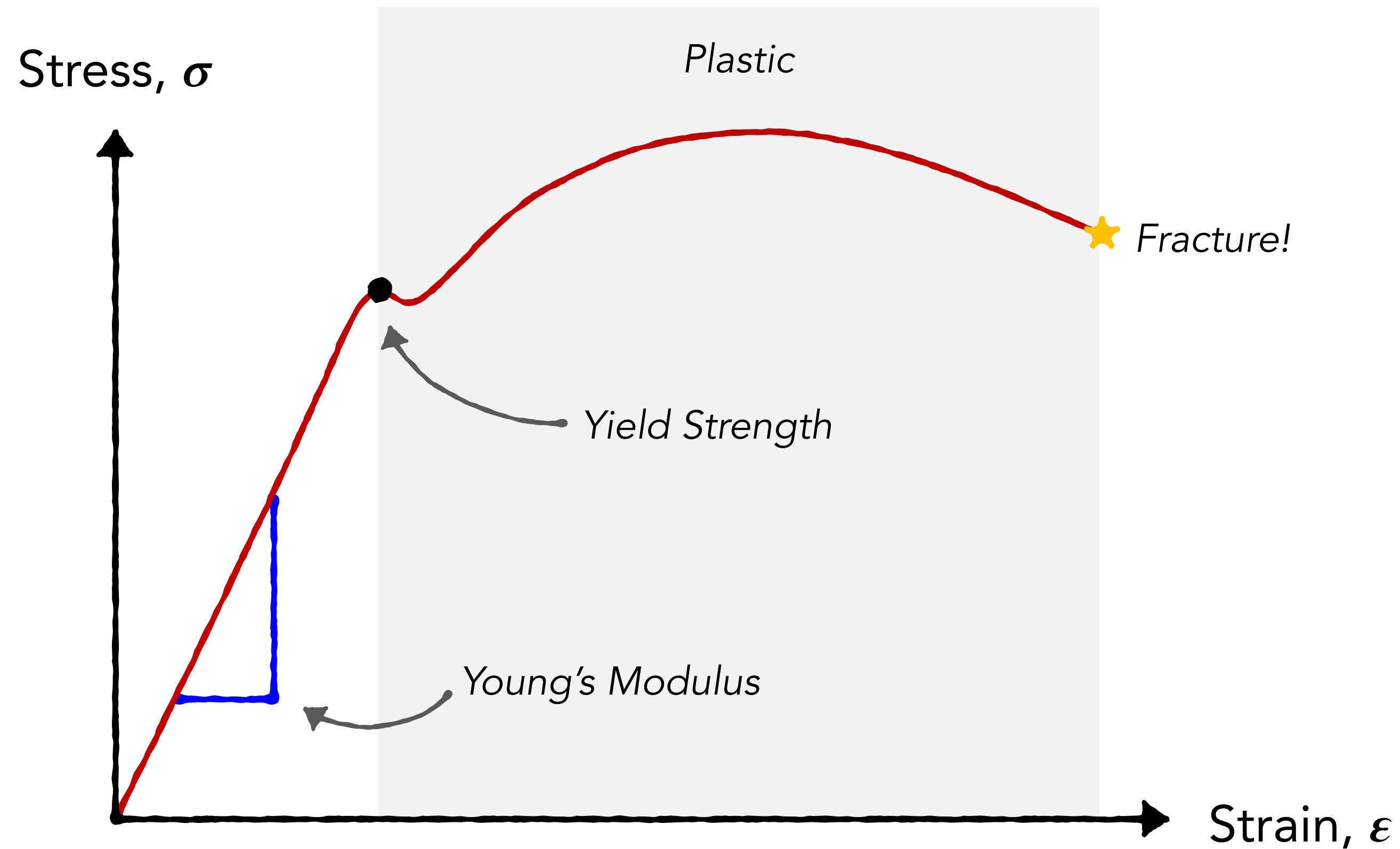
Slope of PSD is a measure of self-affinity, fractal dimensionality.

Self-affine surfaces may allow us to scale up/down our results.

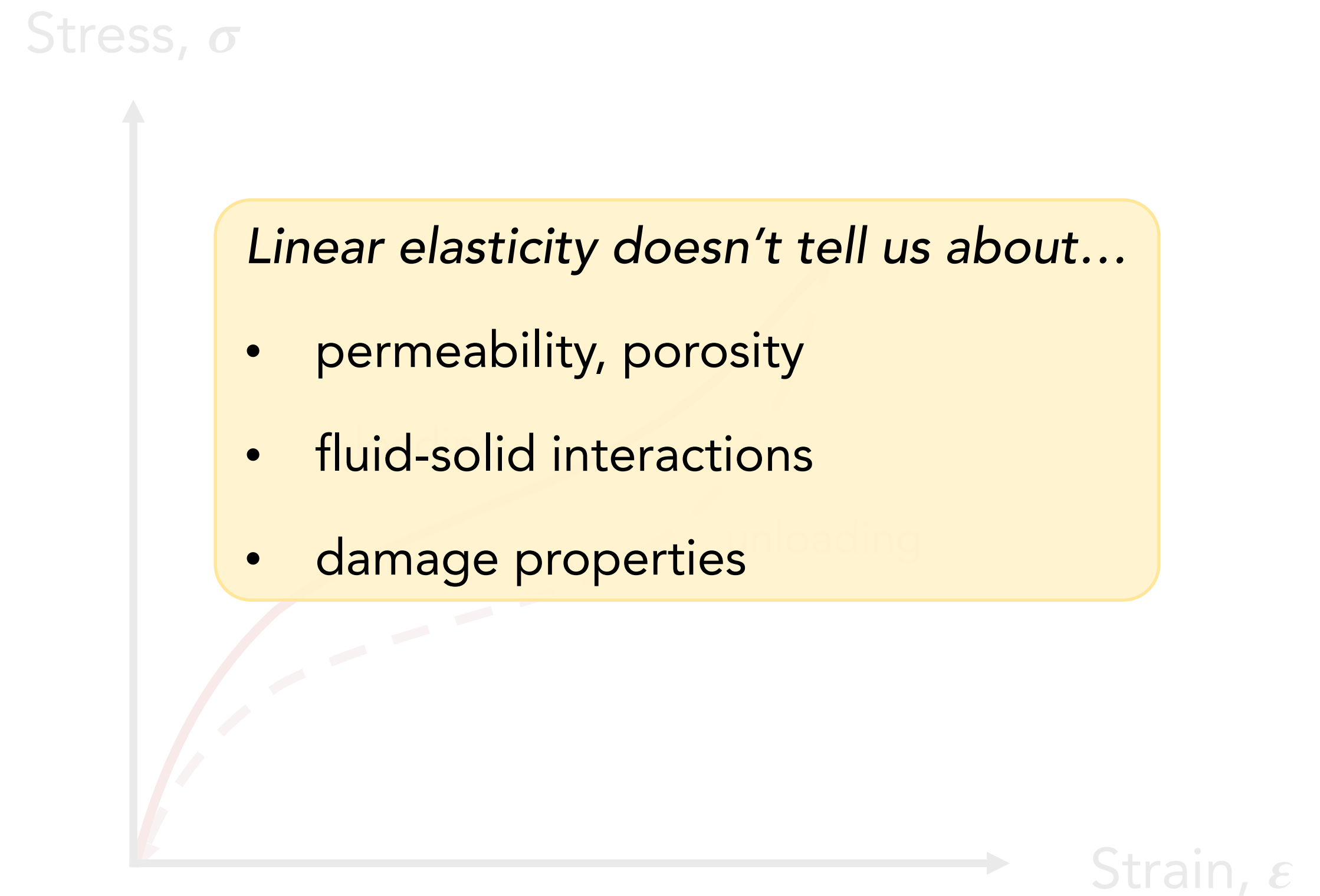


Linear elasticity does not fully capture behavior of rocks

Linear elastic deformation

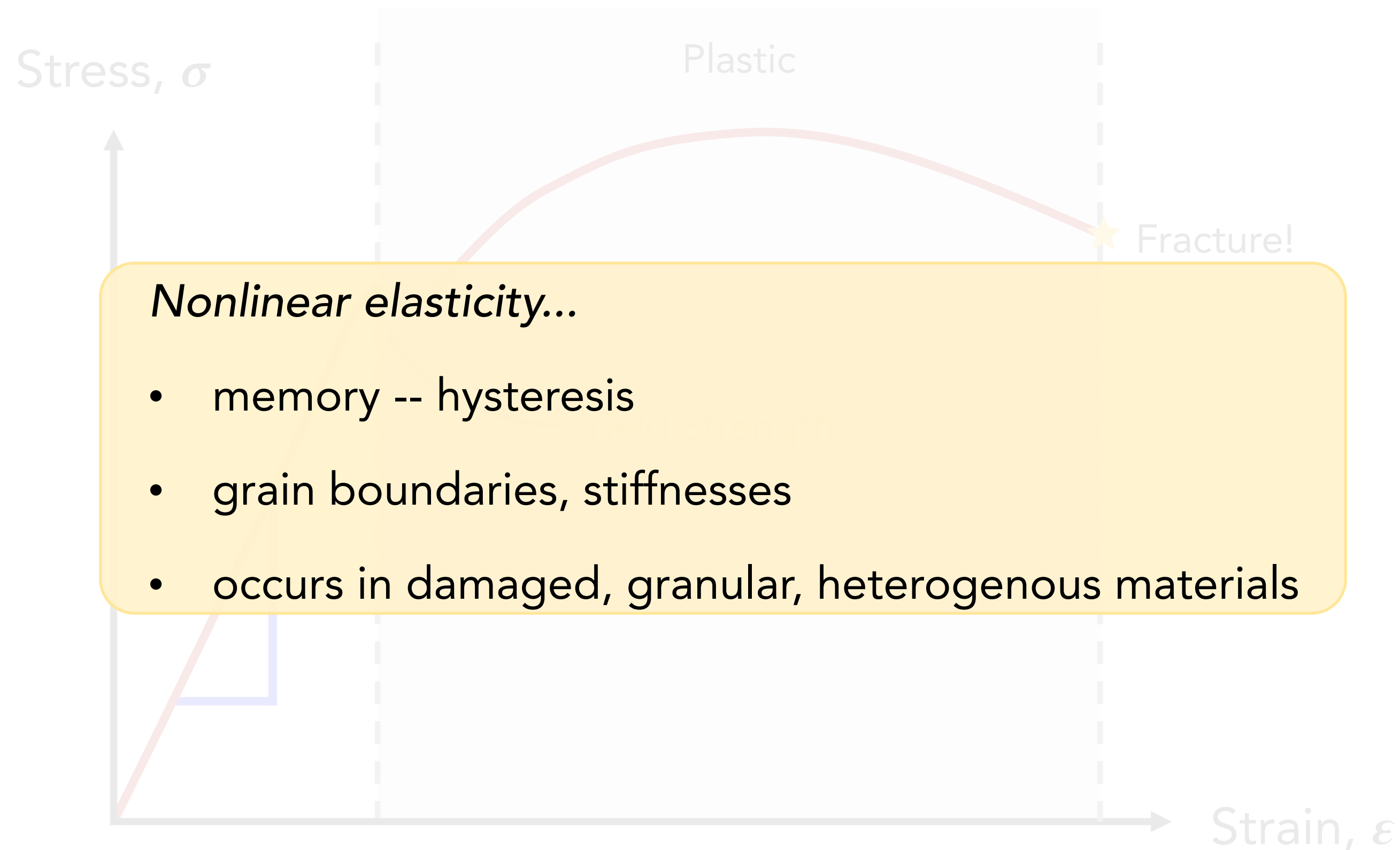


Nonlinear elastic deformation -- rocks

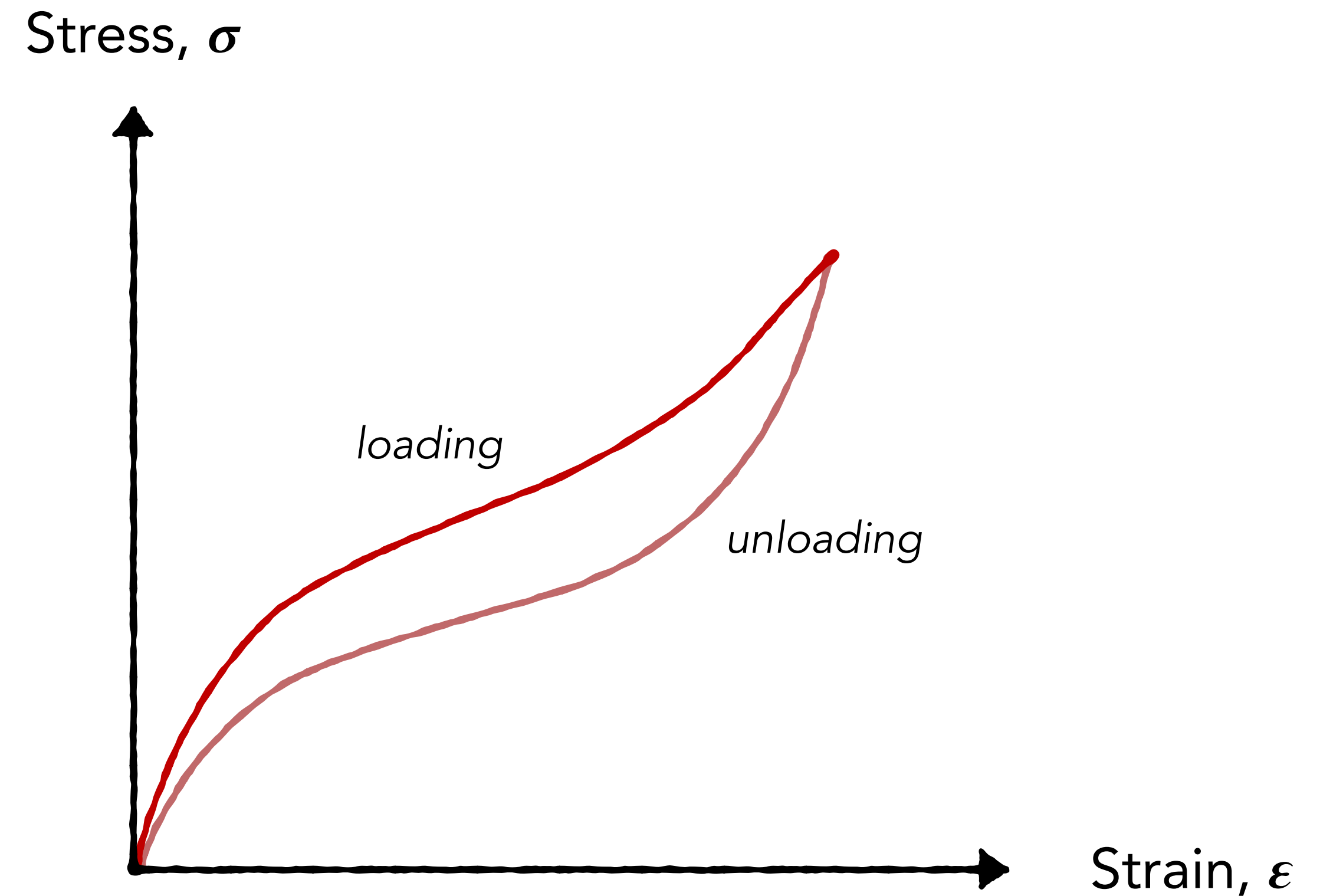


Nonlinear elasticity describes complex mechanical properties of rocks

Linear elastic deformation

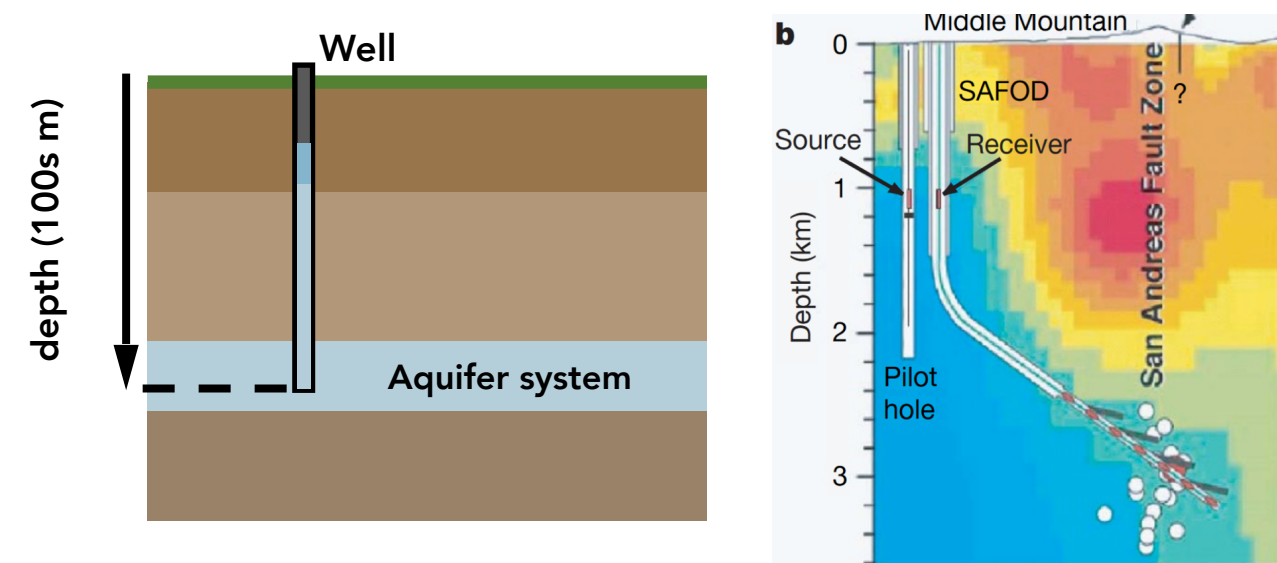


Nonlinear elastic deformation -- rocks

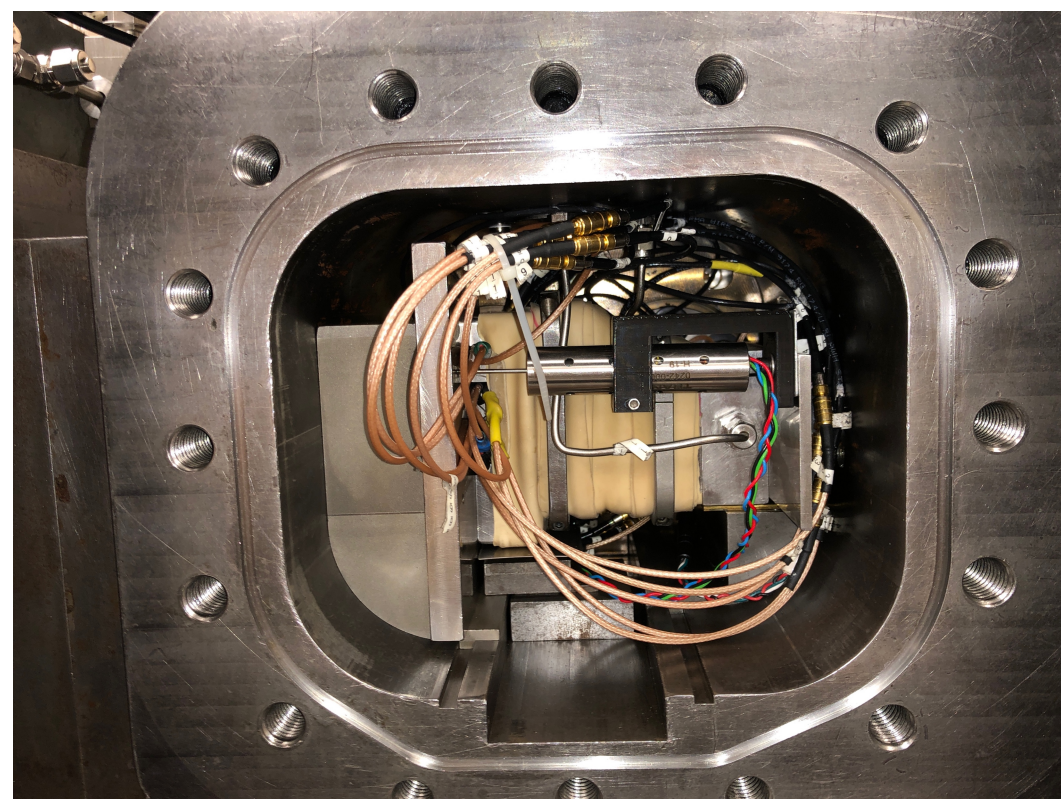


Summary – experimental work

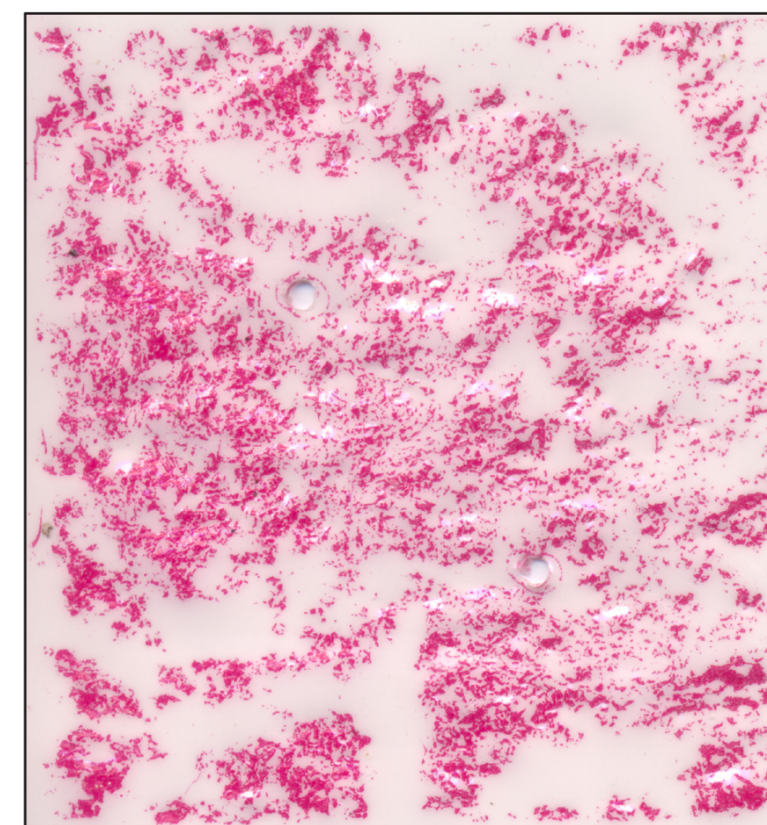
Stress perturbations cause transient softening & permeability change



Simulate field conditions using unique, well-controlled laboratory experiments



Quantifying asperity distribution can elucidate micro- poro- mechanics



Permeability enhancement and nonlinear elasticity decrease with fracture closure

