Fracture static elastic properties inferred from flow measurements

Joseph H.Y. Ma, Qiaomu Qi, Yu Qiu, Yunyue Elita Li, and Arthur Cheng

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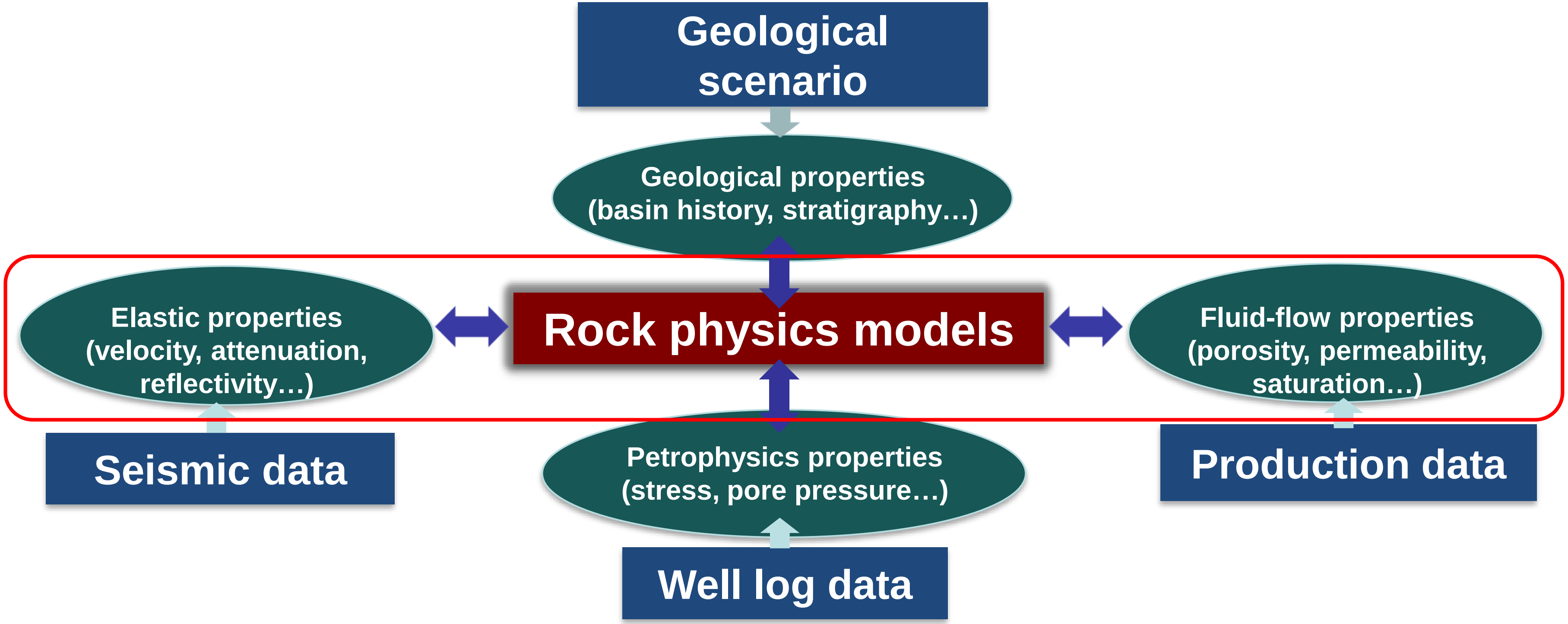
NUS
National University of Singapore

Motivation – Unified Rock Physics Model

- **A model coupling fluid flow and elastic properties in rocks**



Adopted from Li et al. (2015)

Motivation – Importance of Fractures

- **Presence of fractures enhances material and energy exchange**
- **Key components in geological and sub-surface engineering**
  - **Unconventional hydrocarbon production**
  - **Geothermal energy extraction**
  - **Hydrogeological phenomena**

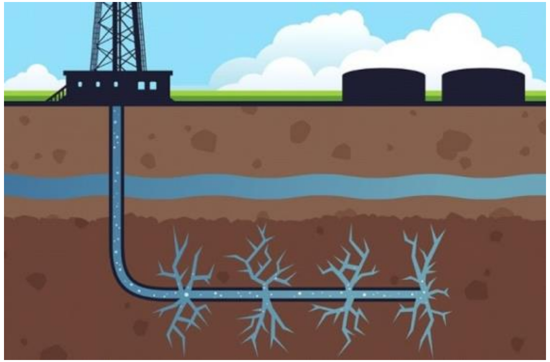


Image: iogsolutions.com

Image: marine.gov

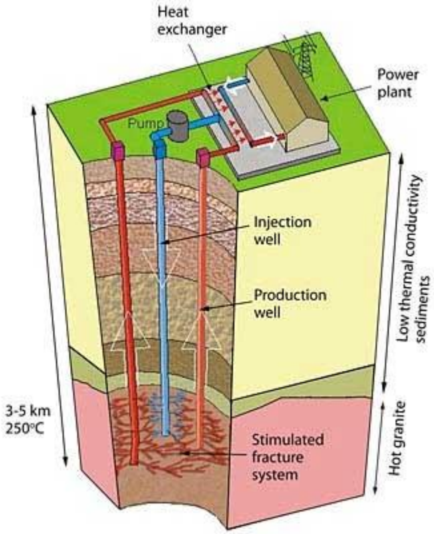


Image: geothermalworldwide.com

Motivation – Elasticity Measurements

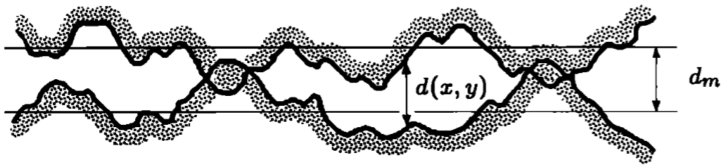
- **Variations between dynamic and static elastic parameters in rocks**
- **Relatively common to obtain dynamic elasticity**
  - **Seismic survey, acoustic logging, pulse transmission experiments**
- **Not necessarily straight forward to get static elasticity**
  - **Direct mechanical measurements unable to conduct in subsurface**

Stress-dependent flow properties also reflect fracture elasticity

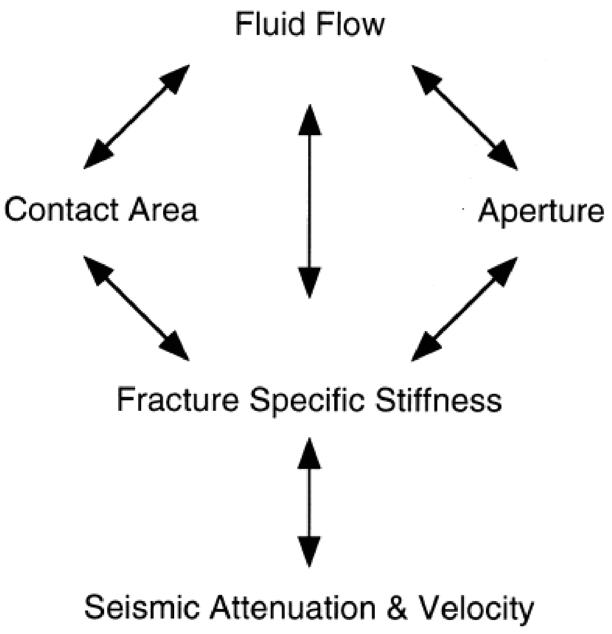
Background

Implicit linkage between fluid flow and stiffness properties in rough fractures

- **Contact areas determines stiffness**
- **Pore volumes determines fluid flow conductivity**



Adopted from Brown (1989)



Adopted from Pyrak-Nolte *et al.* (2000)

Objectives

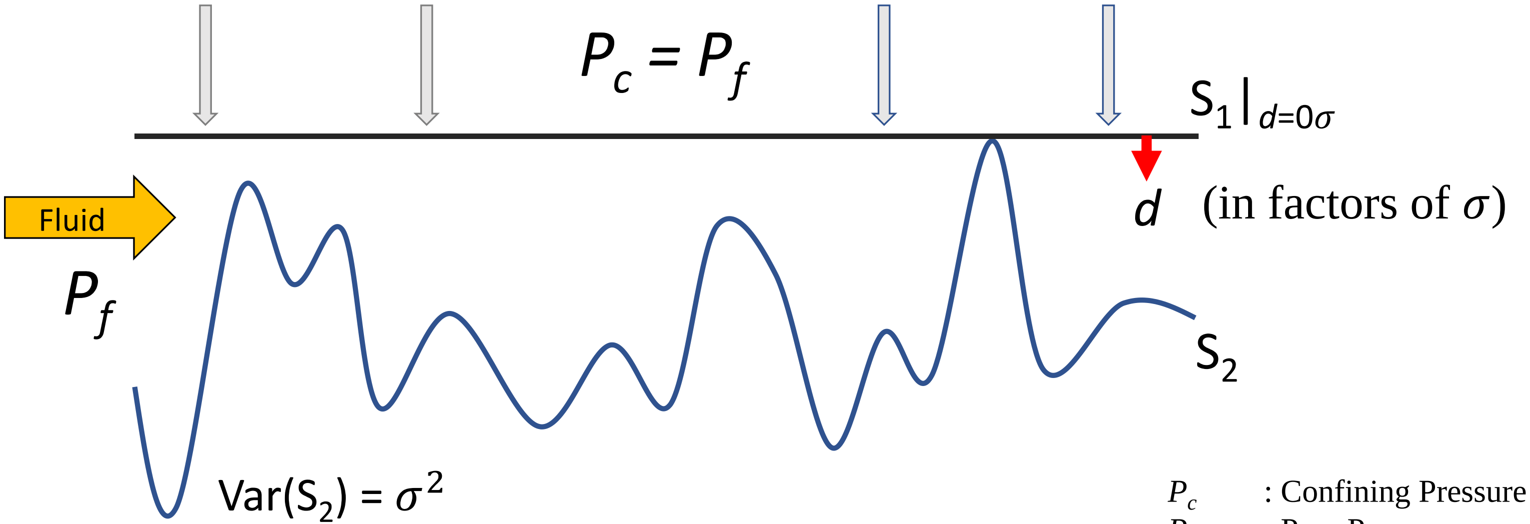
To infer for fracture static elastic properties (e.g. compliance, stiffness, compressibility, stress-free areas) from flow measurements

- **Using steady-state fluid flow properties of different stress levels**
- **Develop relation on mechanical characteristics**

Workflow

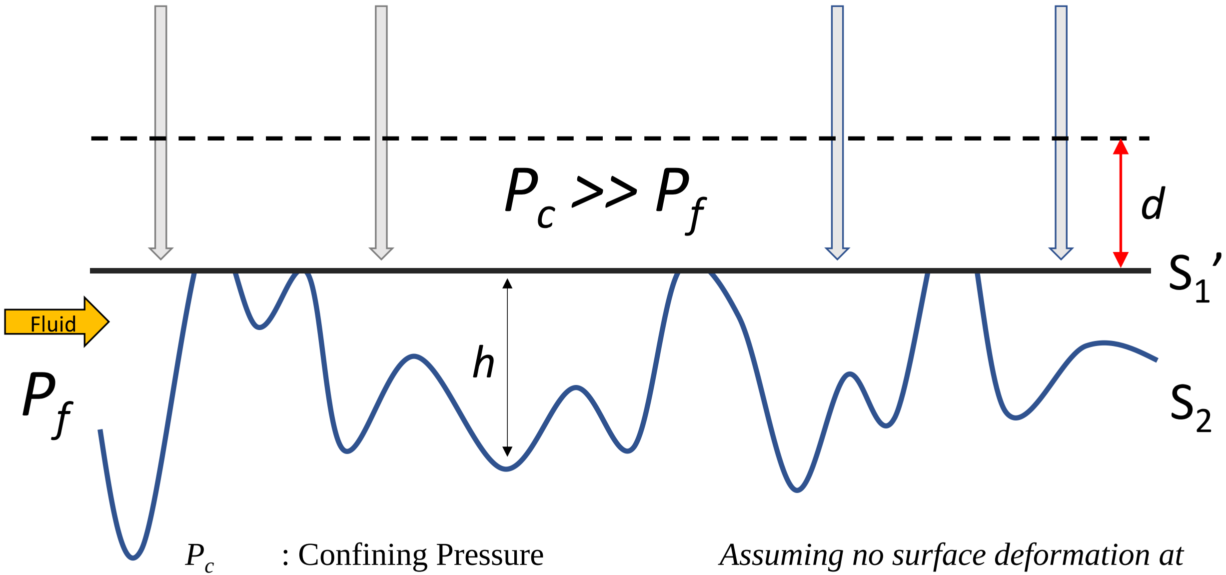
1. Experimental flow measurements on fracture
2. Flow simulation on digitized fracture configurations
3. Inversion for pressure-displacement relationship
4. Inference of fracture static elastic properties

Semi-Rough Fracture Model



P_c : Confining Pressure
P_f : Pore Pressure
P_e : Effective Pressure (P_c- P_f)
d : Compression Displacement

Semi-Rough Fracture Model



P_c : Confining Pressure
P_f : Pore Pressure
P_e : Effective Pressure (P_c - P_f)
d : Compression Displacement

Assuming no surface deformation at uncontacted regions

Increasing effective pressure

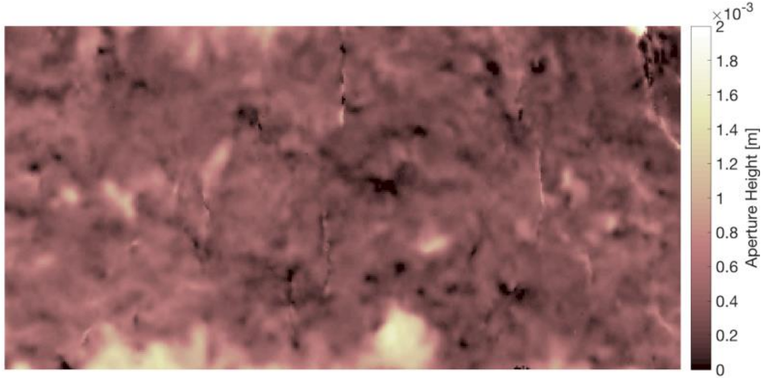
- **Reduces aperture height**
- **Increases contact area**

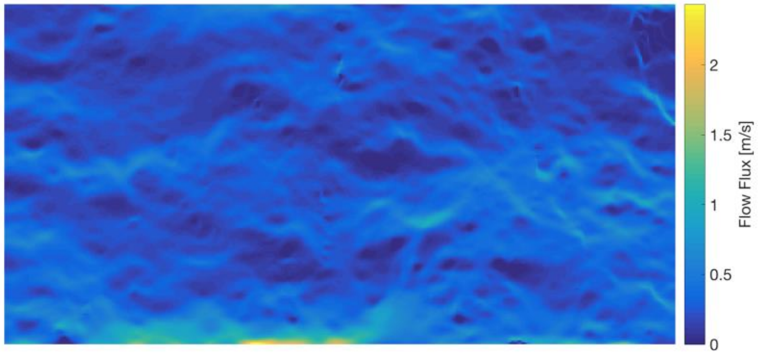
Stress dependency of flow properties

Aperture distribution

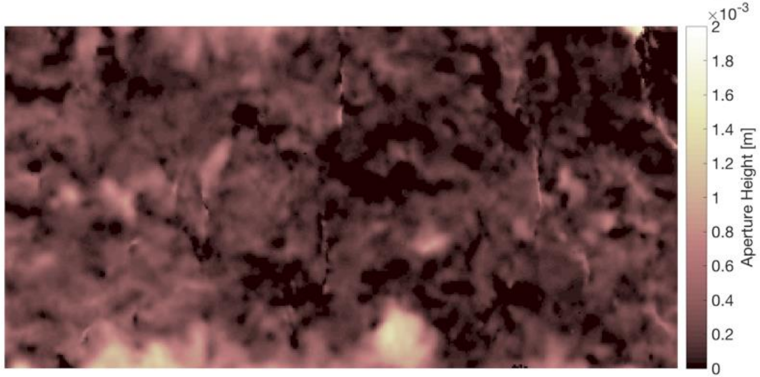
Simulated flow flux field

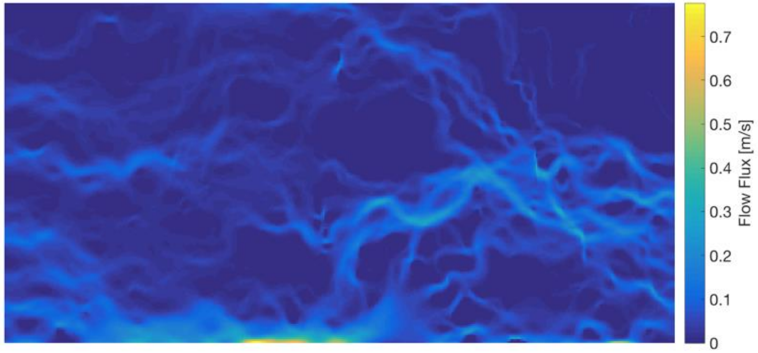
$d = 1.5\sigma$



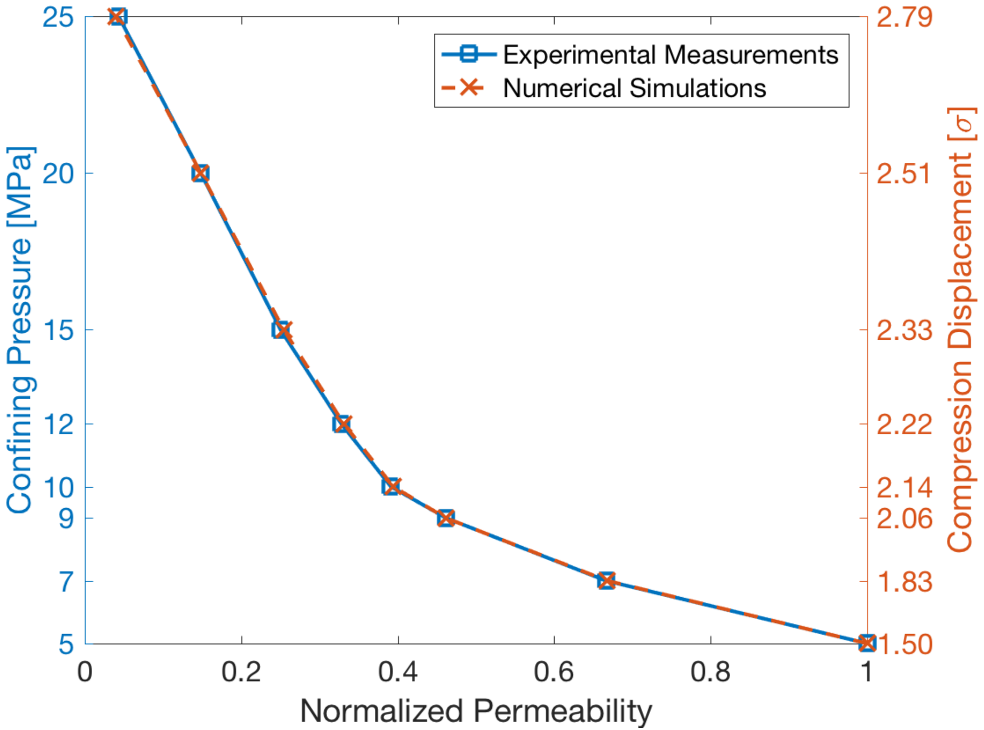


$d = 2.5\sigma$



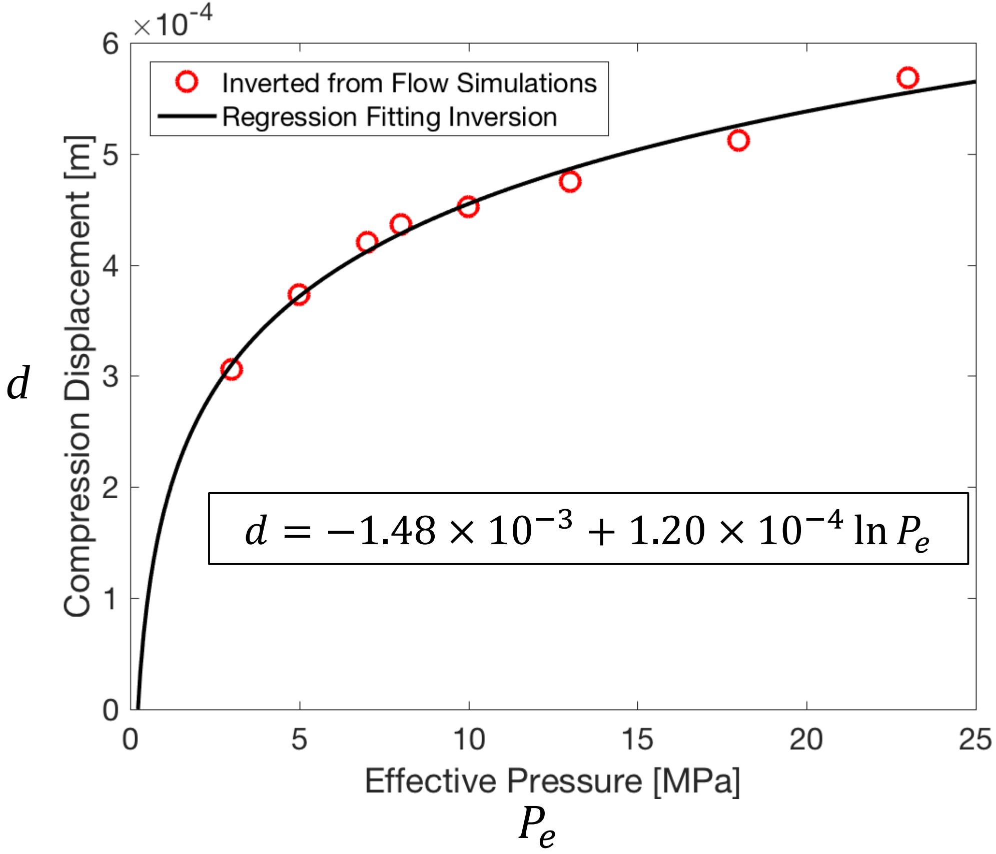


Inversion for *d* - P_e Relation



- **By minimizing the discrepancies between measured and simulated permeability**
- **Correspondence between confining pressure and compression displacement**

Inversion for d - P_e Relation



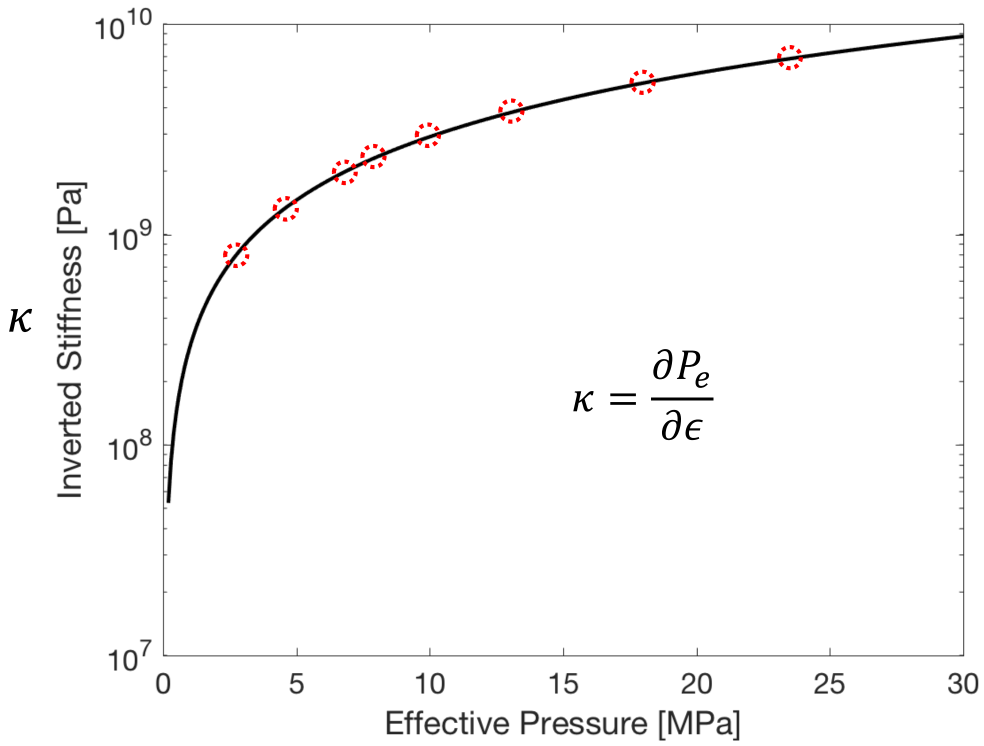
Parametric curve fitting

$$d = a + \sigma_E \ln P_e$$

- Half-joint model assuming exponential-distributed aperture (Swan, 1983)

* $\sigma_{true} = 2.04 \times 10^{-4}$ m

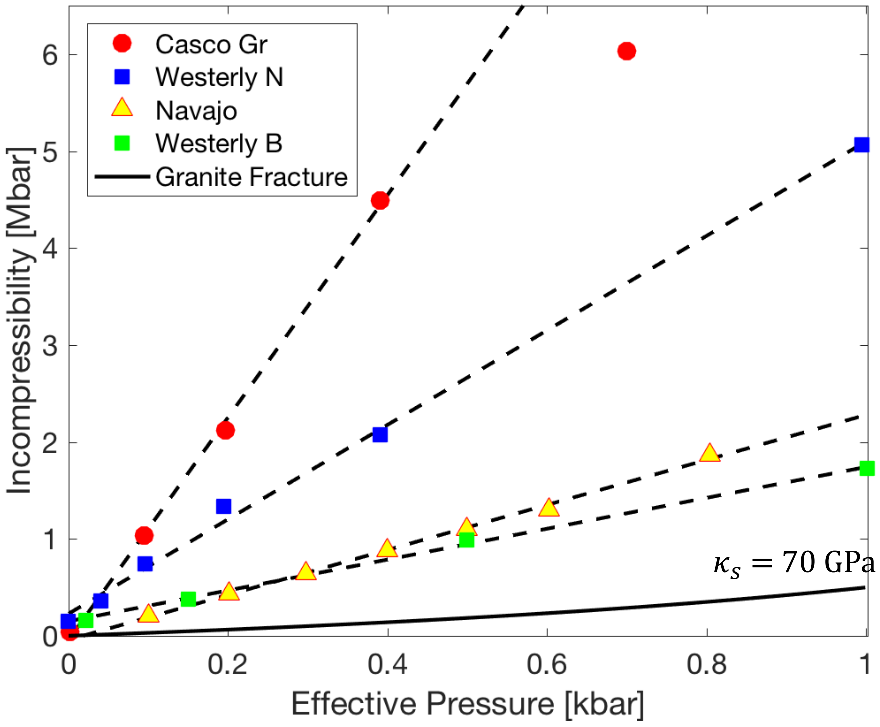
Inverted Fracture Elasticity - Stiffness



- **Logarithmic increase in rock stiffness**
- **Substantial difference in rock stiffness under different pressure**
- **Inverted rock stiffness of several GPa between 5 – 30 MPa effective pressure**

Inverted Fracture Elasticity - Incompressibility

$$\frac{1}{\kappa^{-1} - \kappa_s^{-1}}$$



Modified from Walsh and Grosenbaugh (1979)

Benchmarking with published data

- Linear increase in incompressibility against pressure
- Single fracture "softer" than cracks

Summary

With a known fracture topography, we can obtain

- **Fracture permeability under compression displacement**
  - **Numerical flow simulations based on semi-rough model**
- **A compression displacement – effective pressure relation**
  - **Inverted from the permeability reduction trend from experiment and simulations**
- **Fracture static elastic properties**
  - **Inferred from the inverted mechanical relation**

Acknowledgements

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