Slates: a potential rock type to extract geothermal energy from the underground?

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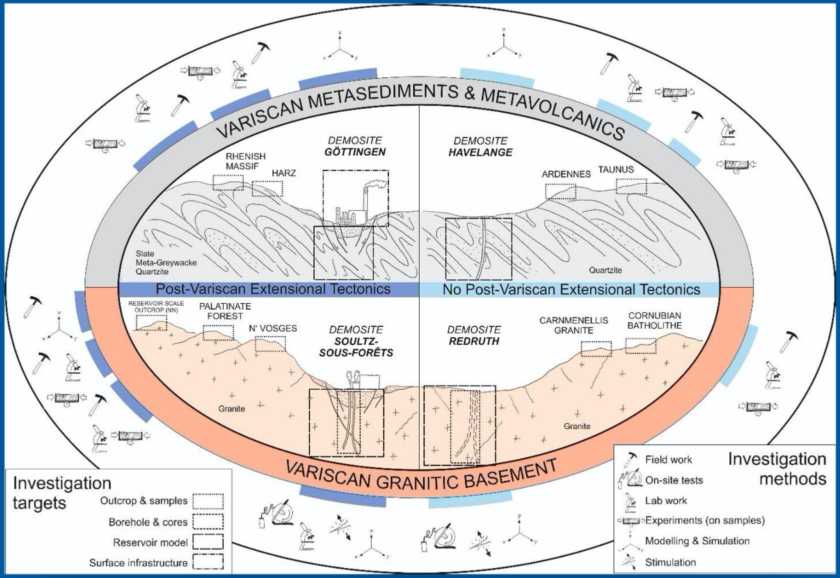

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Content

Motivation

Typically, granitic rocks are considered to act as host rocks for Enhanced Geothermal Systems (EGS) as they are believed to contain a sufficient amount of fractures with an aperture large enough to guarantee an economical production of geothermal energy from the subsurface. Alternatively, metamorphic rocks such as slates/ shales are believed to represent geological environments used for a reasonable heat extraction. Within the framework of the European initiative 'MEET*', we are investigating the influence of p_c, T, σ and surface roughness on the permeability of fractures present in unconventional Variscan reservoir rocks (slates).

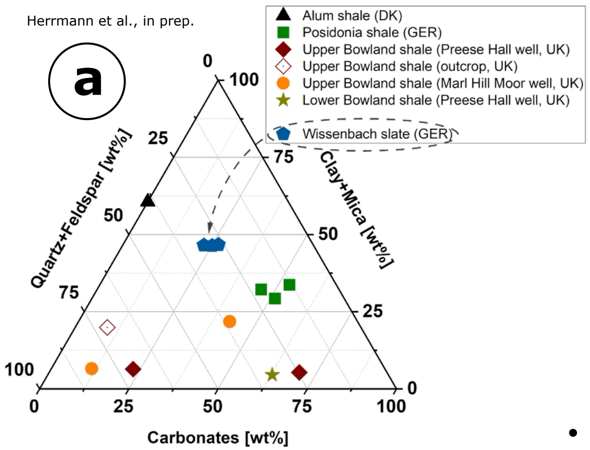
p_c = confining pressure, T = temperature, σ = differential stress acting perpendicular to fracture surface

***M**ultidisciplinary and multi-context demonstration of **E**GS exploration and **E**xploitation **T**echniques and potentials

Sample Material

Composition

Herrmann et al., in prep.



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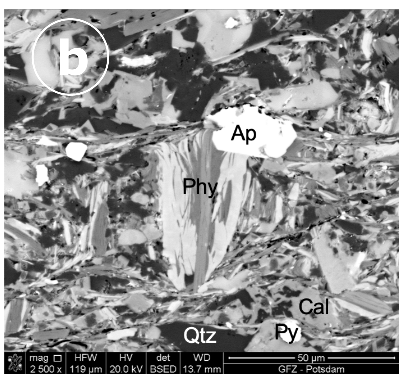
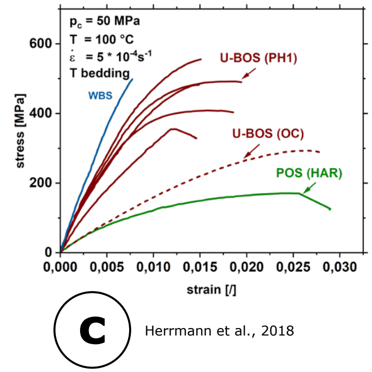
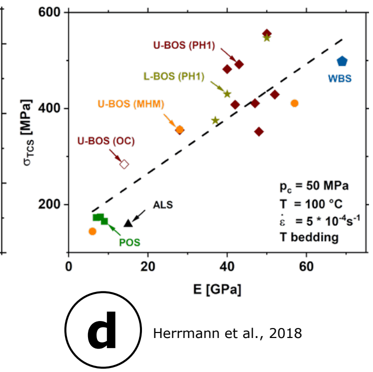
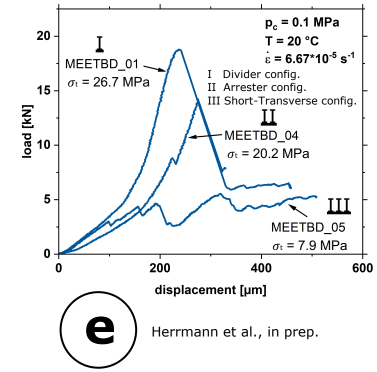


Ap = Apatite, Phy = Phyllosilicate, Qtz = Quartz, Py = Pyrite, Cal = Calcite

Mechanical properties



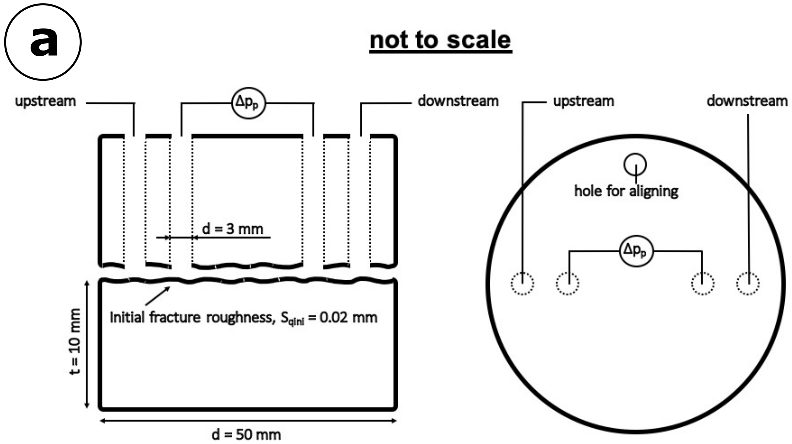


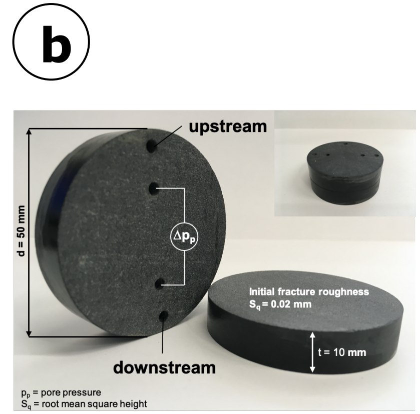


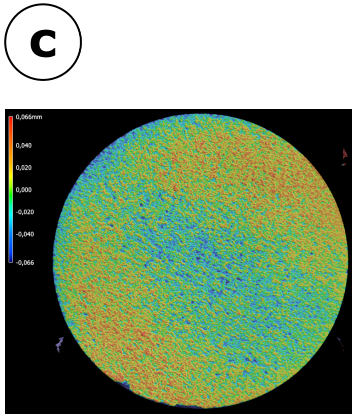
- Core material of Wissenbach shale; ‘Hahnenklee‘ well (z ≈ 1150m)
- Clays+Mica≈50wt%, Carbonates≈25wt%, Quartz+Feldspar≈25wt% **(a+b)**
- Pronounced elastic and only minor plastic deformation at 50 MPa confining pressure, p_c, 100° C temperature, T, and an axial strain rate of $\dot{\varepsilon}$=5x$10^{-4}s^{-1}$ **(c)**
- Mechanical properties (triaxial compressive strength, σ_{TCS} , static Young‘s modulus, E) in line with other European shales **(d)**
- Depending on bedding orientation, tensile strength (from Brazilian Disk testing) ranges from σ_t = 7.9 to 26.7 MPa **(e)**

Experimental Setup

Shale assembly and fracture roughness







(a+b)

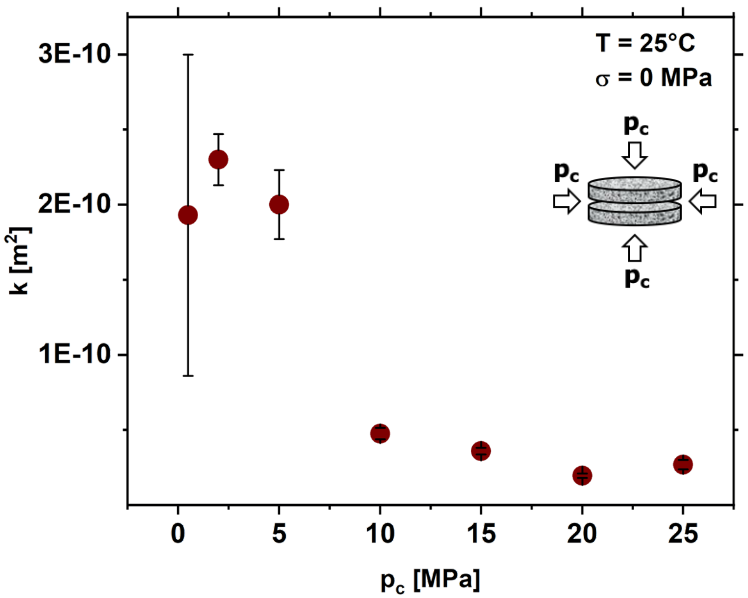
- Sample-setup consists of two cylindrical specimens, each: diameter, d = 50mm and thickness, t = 10 mm
- Prepared perpendicular to bedding orientation
- Radial fluid flow (H_2O) realized through ‘upstream‘ and ‘downstream‘ boreholes
- Differential pressure along fracture, Δp_p, measured at two separate boreholes

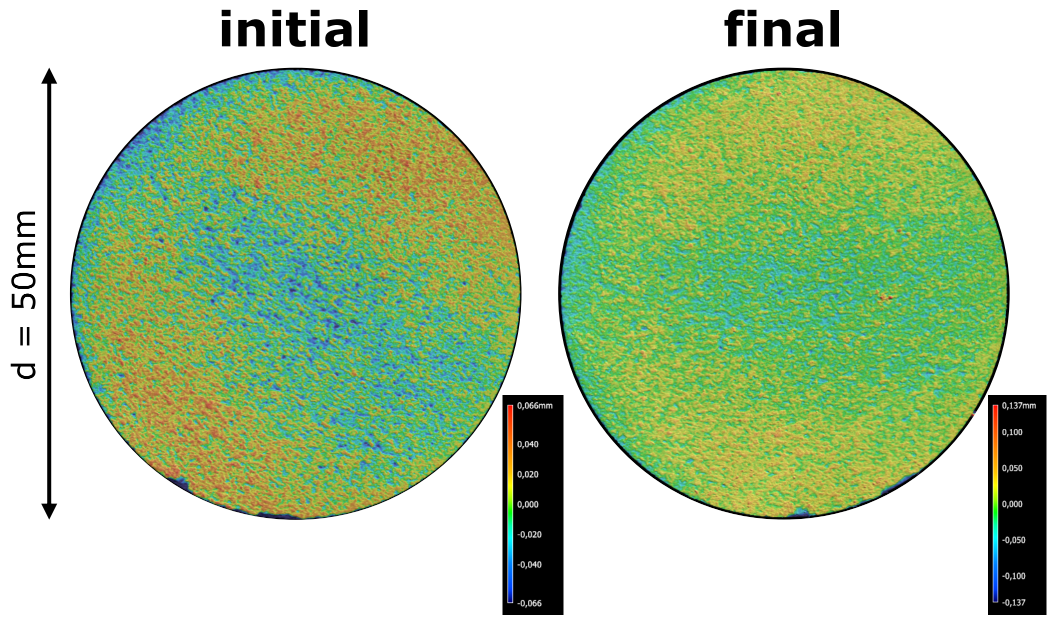
(c)

- For comparison, all fractures were prepared with an average initial surface roughness of $S_q \approx 0.02$mm
- Experimental duration for each experiment: t = 1 -2 weeks

Results

Influence of confining pressure

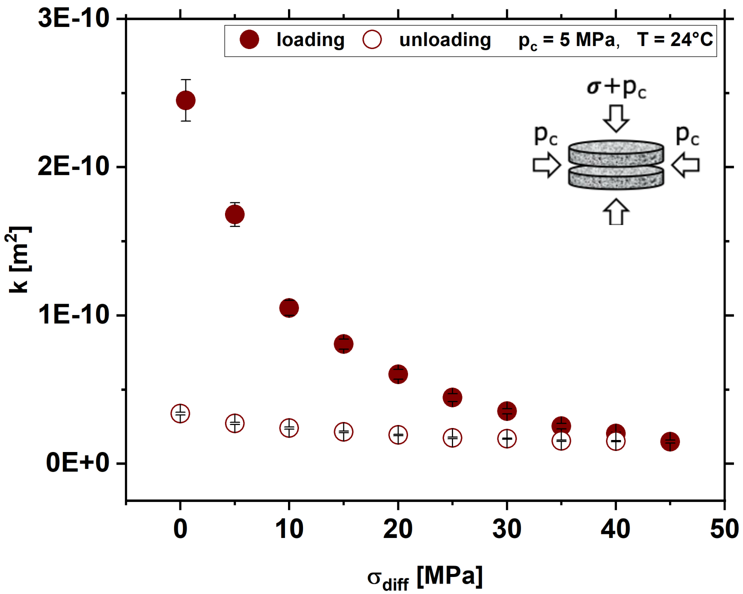


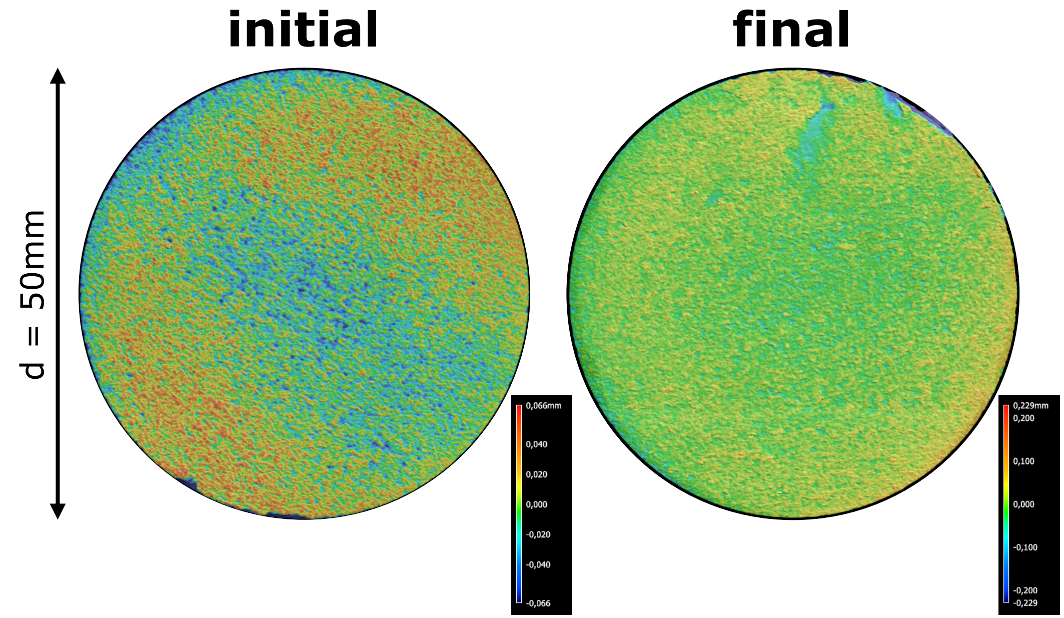


- With increasing p_c, permeability within the fracture, k, is decreasing and approaching a minimum value potentially induced by a change from fluid flow due to an increased fracture surface asperity area
- → also apparent by comparing initial and final fracture surface roughness after the experiment, which reveals a reduced amount of surface asperities (irreversible inelastic deformation)

Results

Influence of differential stress

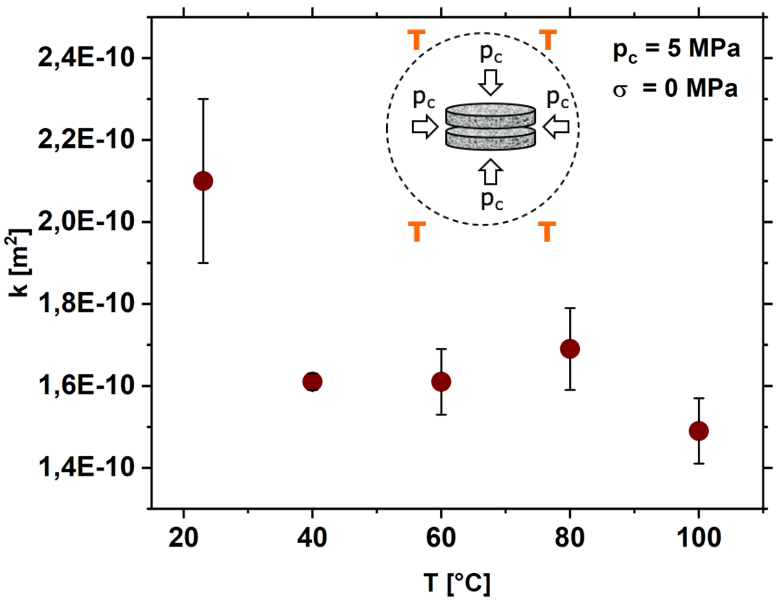


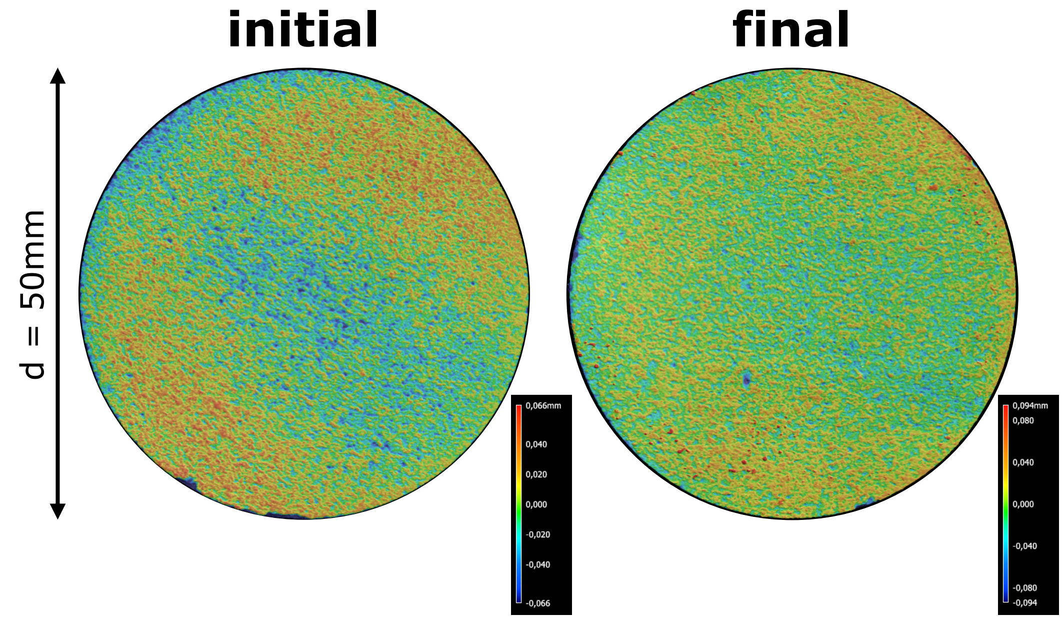


- Influence of σ on k similar to the effect of p_c on k (decreasing k with increasing σ); also with respect to fracture surface asperities
- Recorded unloading curve yields hardly a recovery of k if compared to the initial value at σ = 0 MPa, which proofs our assumption of an irreversible, inelastic deformation of the surface asperities within the fracture

Results

Influence of temperature

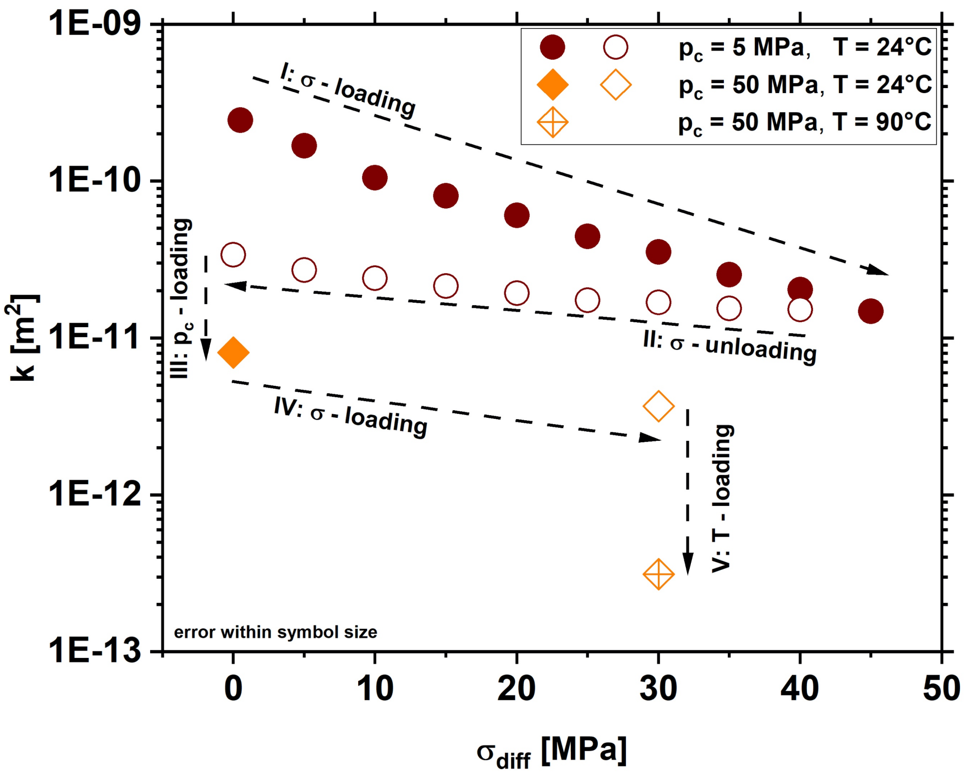




- After a rapid drop with increasing temperature from T = 20 °C to T = 40 °C, k remains almost constant
- In general, higher fracture permeability than those of samples measured at increasing p_c and σ
- → potentially associated with abundant fracture surface asperities of the specimen after the experiment

Results

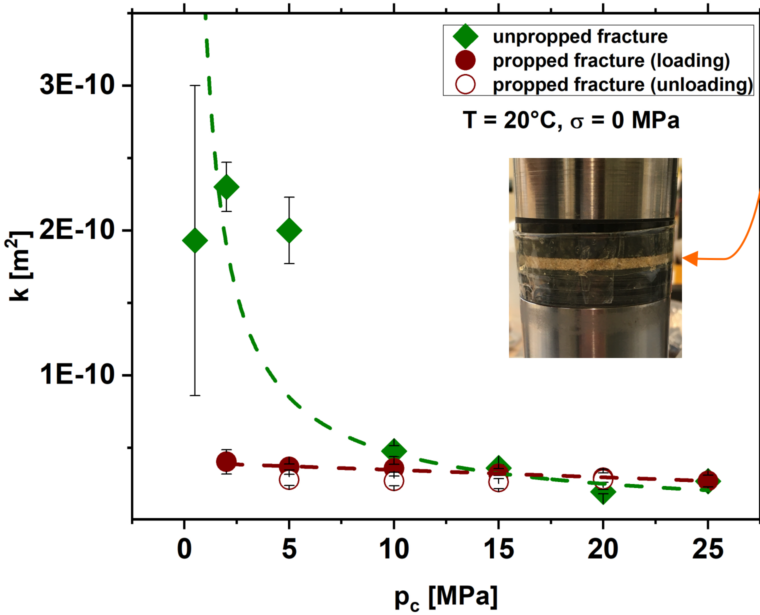
Combined influence of p_c, T and σ

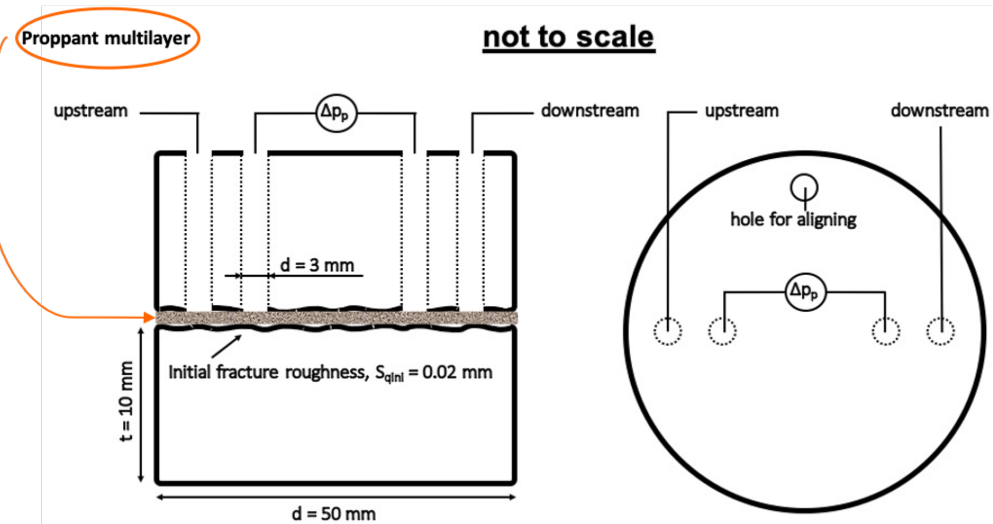


- k ↓ for p_c and σ ↑ , due to irreversible deformation of fracture surface asperities (I+II)
- Even after unloading, k still decreases with increasing p_c (III)
- increasing σ at elevated p_c continues to yield decreasing k values (IV)
- Even after a pronounced deformation history (I - IV), k decreases with increasing T (from T = 24 °C to T = 90 °C), suggesting the presence of fracture sealing processes at elevated temperatures

Results

Influence of proppant agents



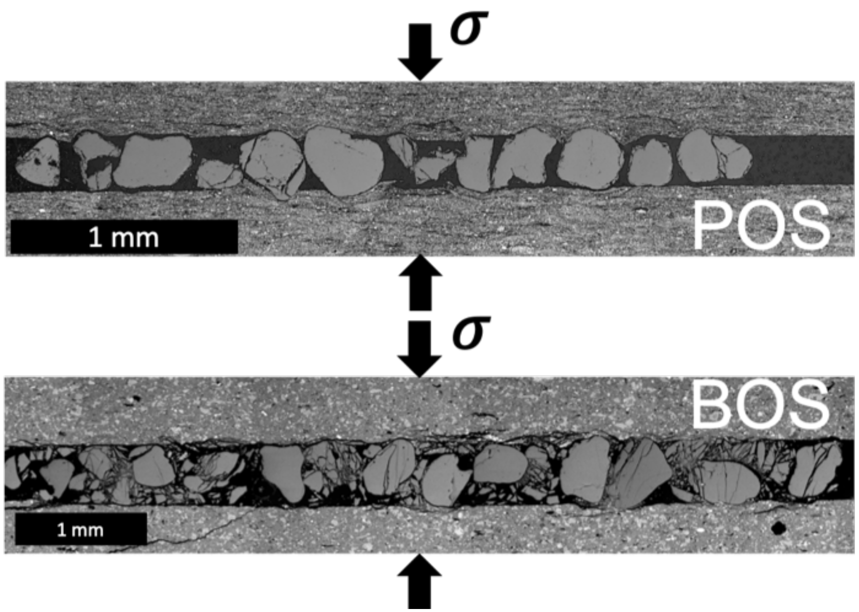


- Propping the fracture with a multilayer of Quartz grains yields a tremendously less influence of p_c on k, if compared to samples containing only self-propped fractures
- Additionally, the amount of inelastic, irreversible deformation seems to be little as changes of k values prior to and after loading are relatively small
- The usage of proppant agents to maintain conductive pathways within slate reservoirs may only be considered at confining pressures larger than $p_c \approx 20$ MPa

Conclusions

- Permeability, k, of fractures decreases with increasing confining pressure and axial differential stress approaching a constant k – value
- After an immediate drop at T ≈ 40°C temperature, fracture permeability remains nearly constant up to 100°C
- Evolution of fracture permeability correlates with evolving fracture surface roughness suggesting a change in the fluid flow patterns within the fracture (irreversible deformation of the fracture surface)
- The influence of p_c, T and σ on fracture permeability reduction is relatively low, suggesting that slates may be considered as potential EGS host rocks
- → especially if one assumes the usage of proppant which tremendously reduces the influence of mechanical loading on the fracture permeability

Outlook



- Investigate in detail the influence of proppant embedment on the long-term fracture permeability; Proppants
  - ➢ may embed in relatively weak, clay-rich reservoir rocks, such as the Posidonia (POS) shale → leading to a reduced fracture permeability due to fracture closure
  - ➢ Or crush in relatively strong, quartz-rich host rocks, e.g., Bowland (shale) → yielding a lowered fracture permeability as a result of sealed fractures due to fines production and migration

- Additionally, fracture surface roughness and shear strain may have a severe effect on the fracture permeability and therefore will be investigated by setting up, perform and evaluate according flow experiments