Fracture reactivation for permeability enhancement in geothermal systems

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The problem:

- What is the propensity for variably sealed fractures to be reactivated during deformation?
- What is the role this fracture reactivation plays on permeability?

The materials: We source un-jointed, bedded sandstones and the same bedded sandstones containing a single, variably-sealed joint from a unit of Permo-Triassic sandstone sampled from the EPS-1 borehole near Soultz-sous-Forêts (France) in the Upper Rhine Graben.

3 sandstones were sampled from 3 different depths down the borehole:

- Sandstone 117 – porosity: 0.08 – 0.11; barite-filled joints; **joints are moderately-sealed** (i.e. some porosity is observed at sample scale)
- Sandstone 179 – porosity 0.10 – O.12; quartz-filled joints; **joints are poorly-sealed**
- Sandstone 388 – porosity 0.13 – 0.16; barite-filled joints; **joints are well-sealed**

20 x 40 mm samples were cored such that their dominant structural feature (i.e. bedding or natural joint) was oriented parallel, perpendicular, or obliquely to the sample axis:

0-10°: structure is parallel
11-79°: structure is oblique
80-90°: structure is perpendicular

Joint is parallel

Joint is oblique

Joint is perpendicular

The methods:

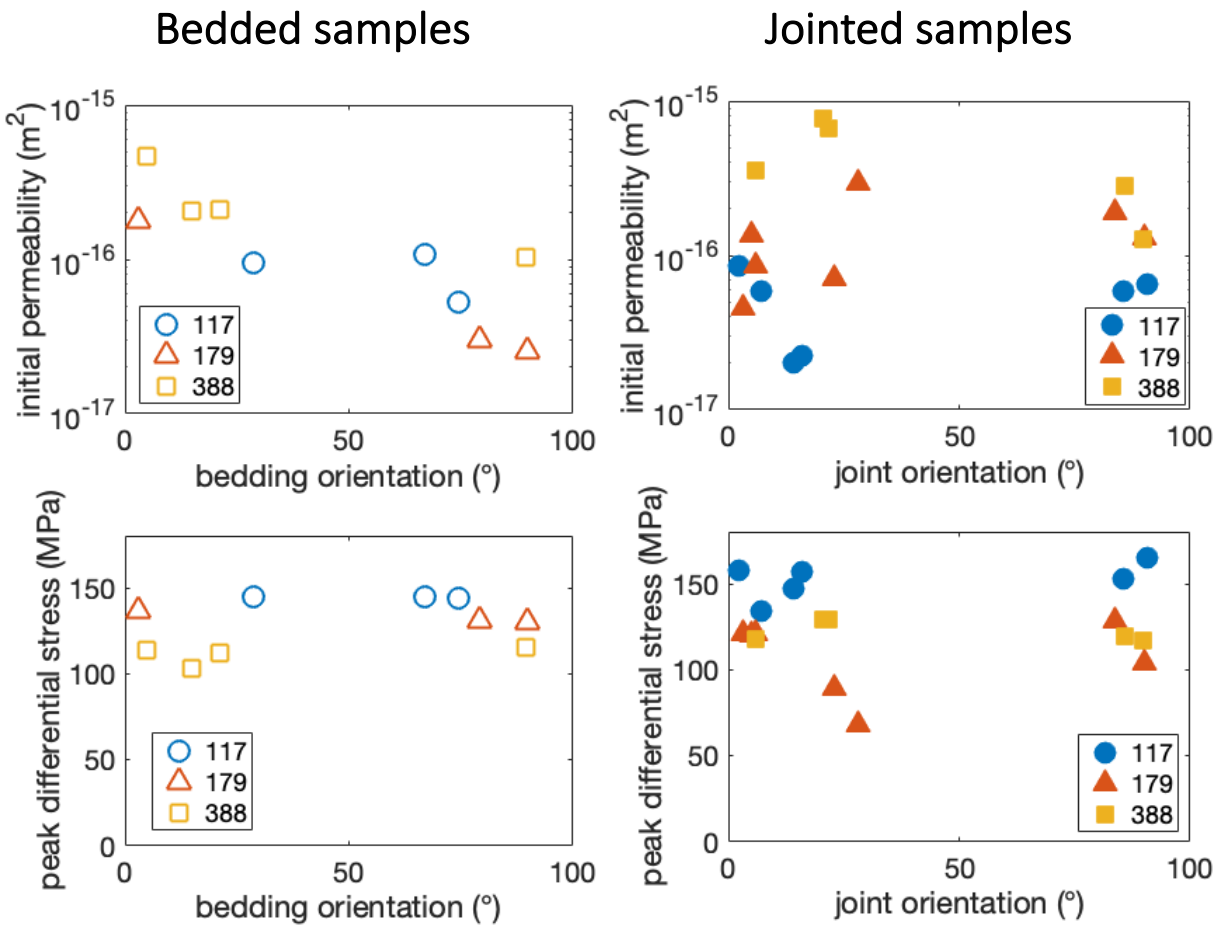
- Sample permeability was measured before and after deformation.
- Deformation conditions:
  - P_c = 15 MPa, P_p = 0.5 MPa
  - Strain rate: 10^{-6} s^{-1}, samples were deformed to 1.5% strain
- Structure (bedding / natural joint / experimentally induced fracture) orientations are measured using Image J.

What we found: *Pre-deformation*

- In un-jointed samples: permeability decreases as a function of increased bedding angle.
- In jointed samples: joint orientation does not appear to have a systematic influence on permeability.

What we found: *Post-deformation*

- In un-jointed samples: bedding angle does not appear to influence peak differential stress
- In jointed samples: overall, joint orientation does not appear to influence peak differential stress, with the exception of samples containing oblique, poorly-filled natural joints



Post-deformation images of samples containing oblique joints

117
Moderately-sealed joint

Experimentally-induced fracture **does not use joint**

179
Poorly-sealed joint

Experimentally-induced fracture **uses joint**

388
Well-sealed joint

Experimentally-induced fracture **does not use joint**

What we found: *Post-deformation*

- All samples developed through-going shear fractures.
  - Only in samples containing poorly-sealed joints did the experimentally produced fractures take advantage of the pre-existing joint.
  - In samples containing a fully-sealed joint, the experimentally induced fracture developed in a previously undeformed part of the sandstone matrix.

- Post-deformation permeability measurements indicate that while sample permeability increased by up to three orders of magnitude for a given sample, this increase is generally independent of feature orientation.

Implications

- This study suggests that the mechanical reactivation of well-sealed joints is difficult, with possible ramifications for reservoir stimulation activities.