Universiteit Utrecht

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Utrecht, the Netherlands

The effect of CO_2 on the mechanical behaviour of anhydrite-filled faults

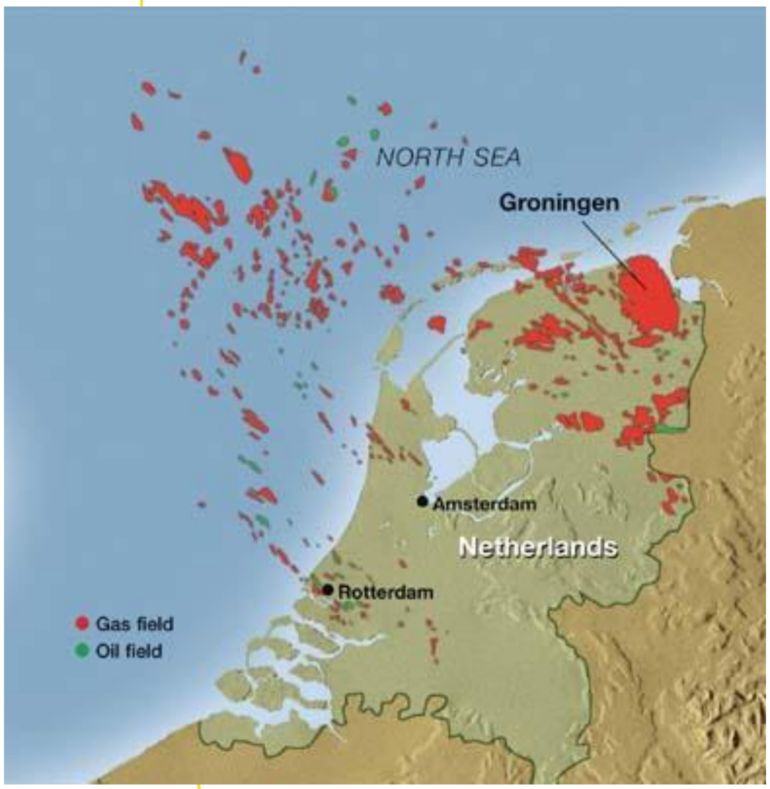
Results within WP3.3 - storage

Anne Pluymakers

UKCCSRS-CATO meeting, 25 March 2014

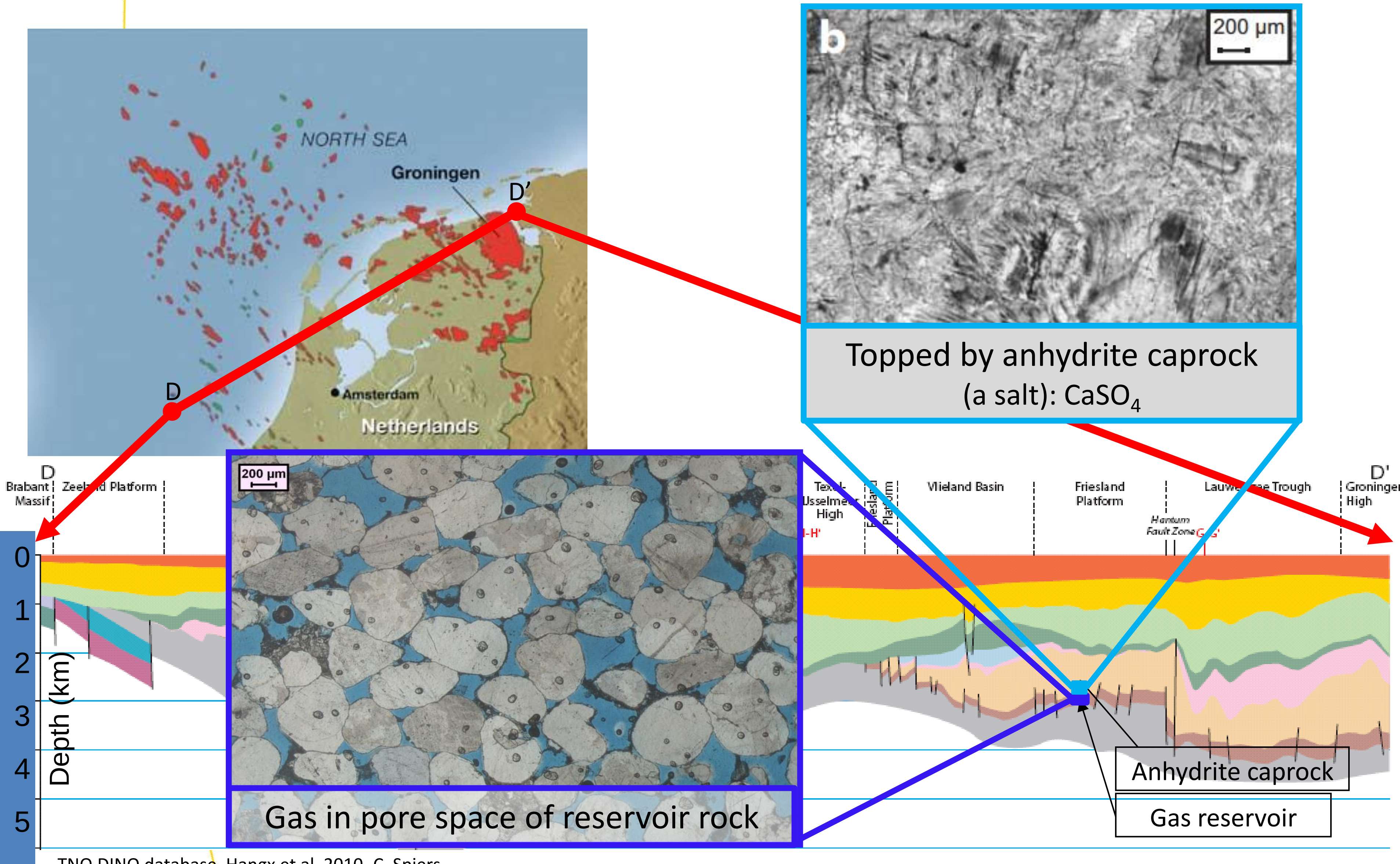
This research is part of CATO-2

CO_2 storage in empty gas fields in the Netherlands



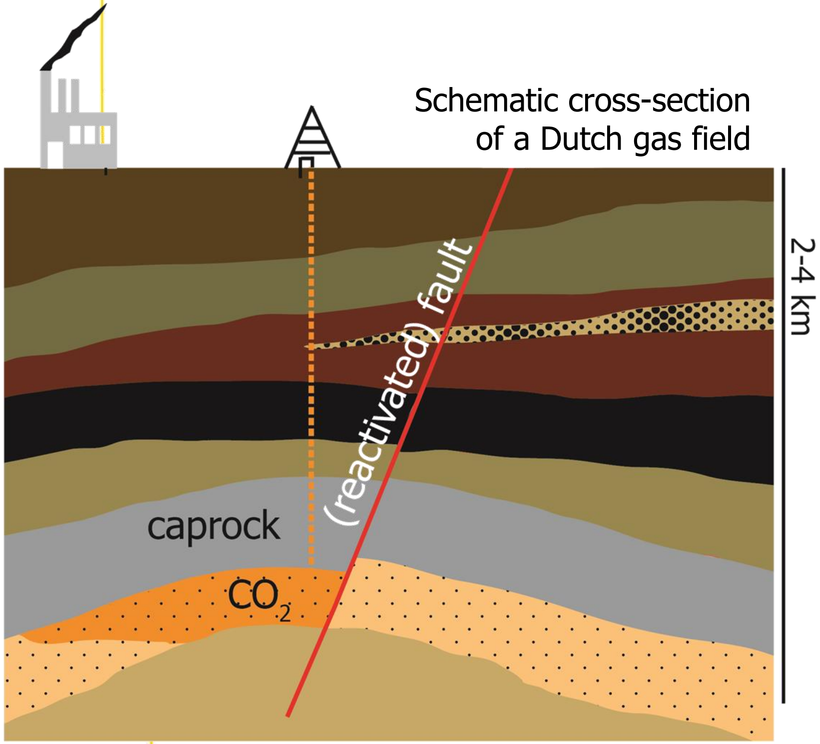
Gas fields in the Netherlands
www.energy-pedia.com

In the North of the Netherlands the caprock consists of anhydrite



TNO DINO database, Hangx et al, 2010, C. Spiers

Geological faults are likely leakage pathways[1)]



Reservoirs are often bounded by faults

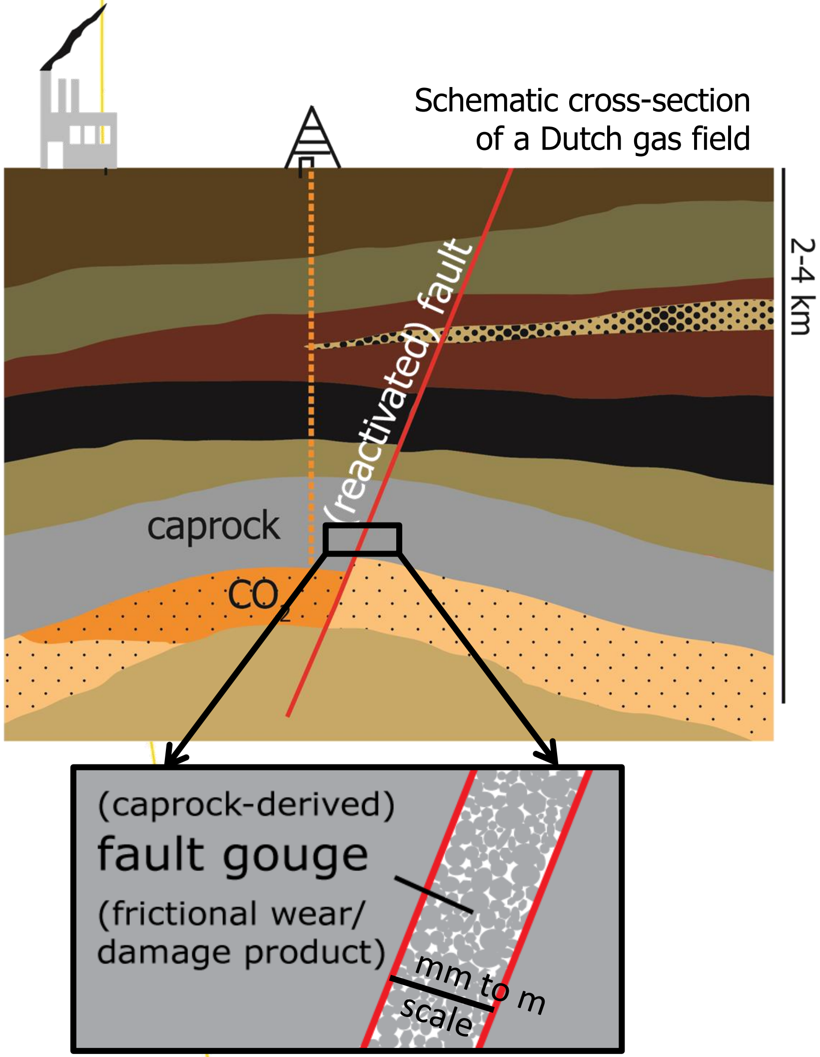
Outcrop of geological fault at Earth surface

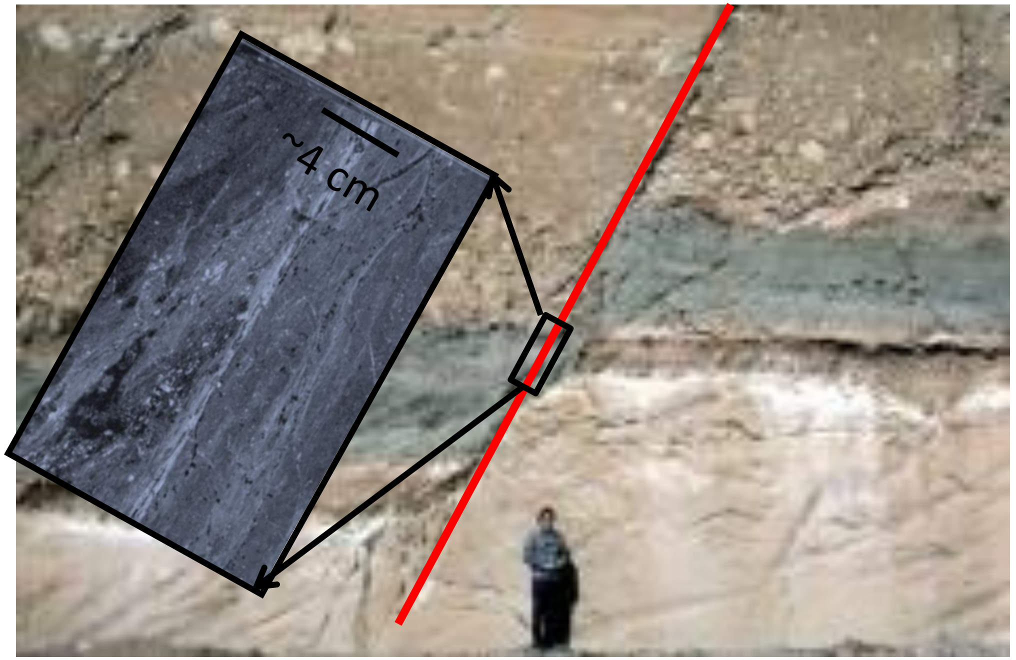
http://geomaps.wr.usgs.gov/archive/socal/geology/inland_empire/socal_faults.html

[1)] e.g. Quattrochi, 2010; Voltatorni, 2009

Geological faults are likely leakage pathways[1)]

Schematic cross-section of a Dutch gas field





Faults are filled with fine powder: fault gouge

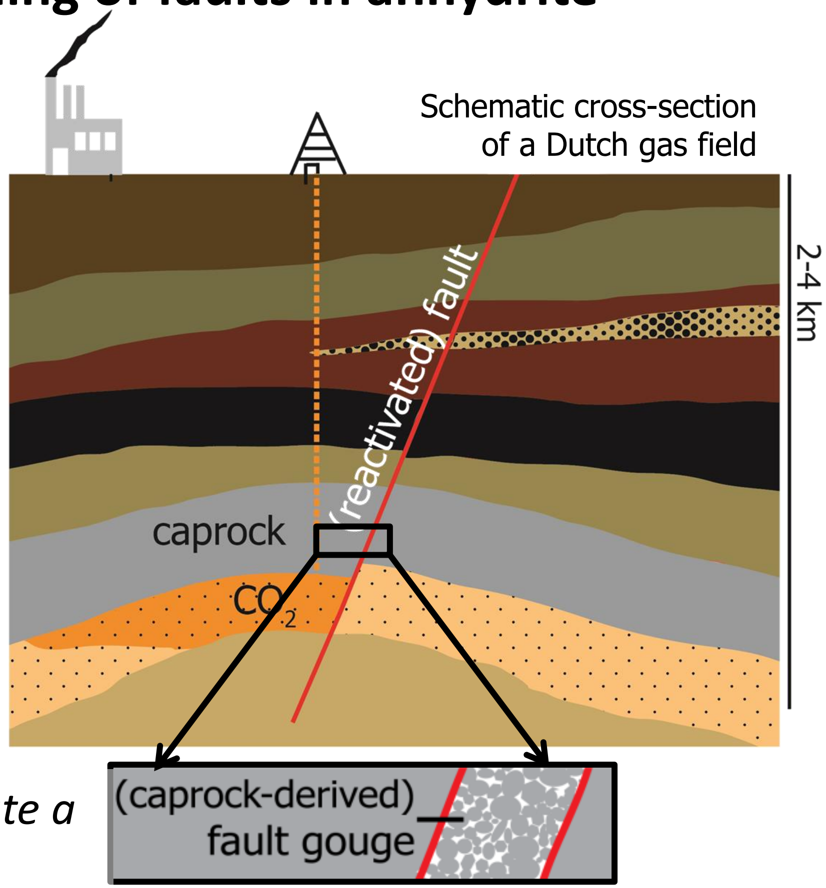
[1)] e.g. Quattrochi, 2010; Voltatorni, 2009

My project: friction and sealing of faults in anhydrite

CO_2 injection changes the reservoir pressure

→ Fault reactivation, sealing capacity and seismicity?

My PhD project:
the effects of CO_2 on the mechanical properties of (simulated) anhydrite fault rock.



Today

1) Does it become easier or more difficult to reactivate a fault in anhydrite when CO_2 is present?

2) If a fault is reactivated, will motion be (micro)seismic?

3) Once fault motion stops, how long before the fault is impermeable again?

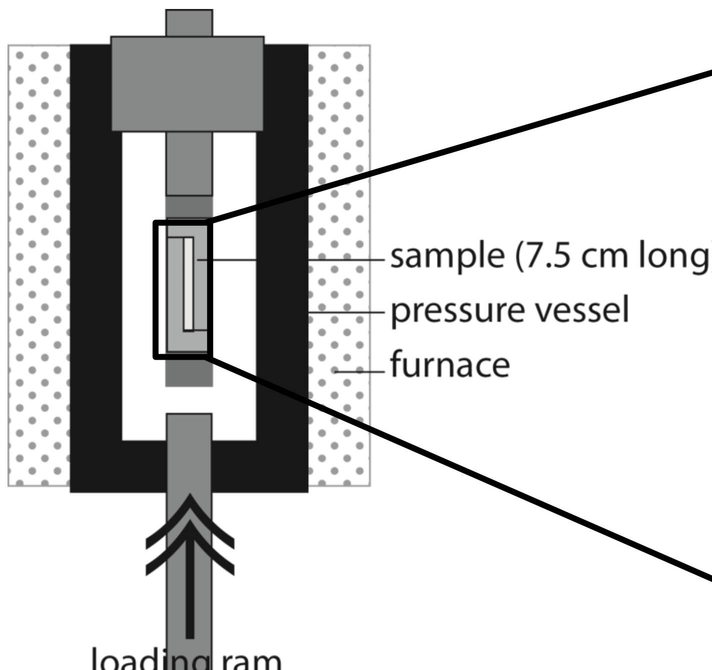
Direct shear experiments: simulated fault slip

1) How easy/difficult is it to reactivate a fault?

2) If a fault is reactivated, will motion be (micro)seismic?

→ Simulated fault slip experiments

Reservoir/caprock in situ conditions :
Temperature: 80 –150°C; pressure: 250 bars
Effect of fluid: dry / wet / CO_2 / CO_2-saturated water



Schematic triaxial pressure cell

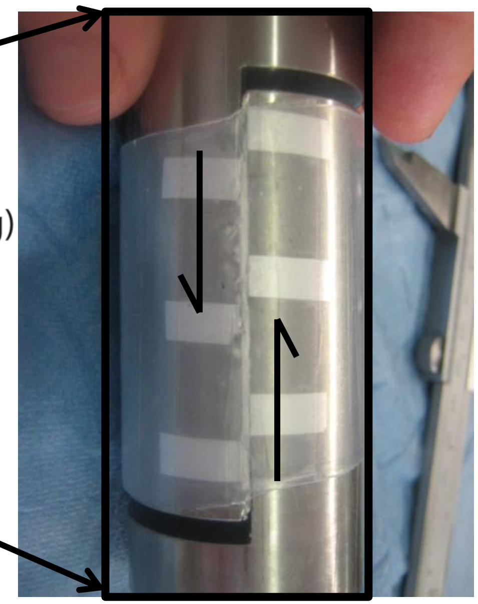
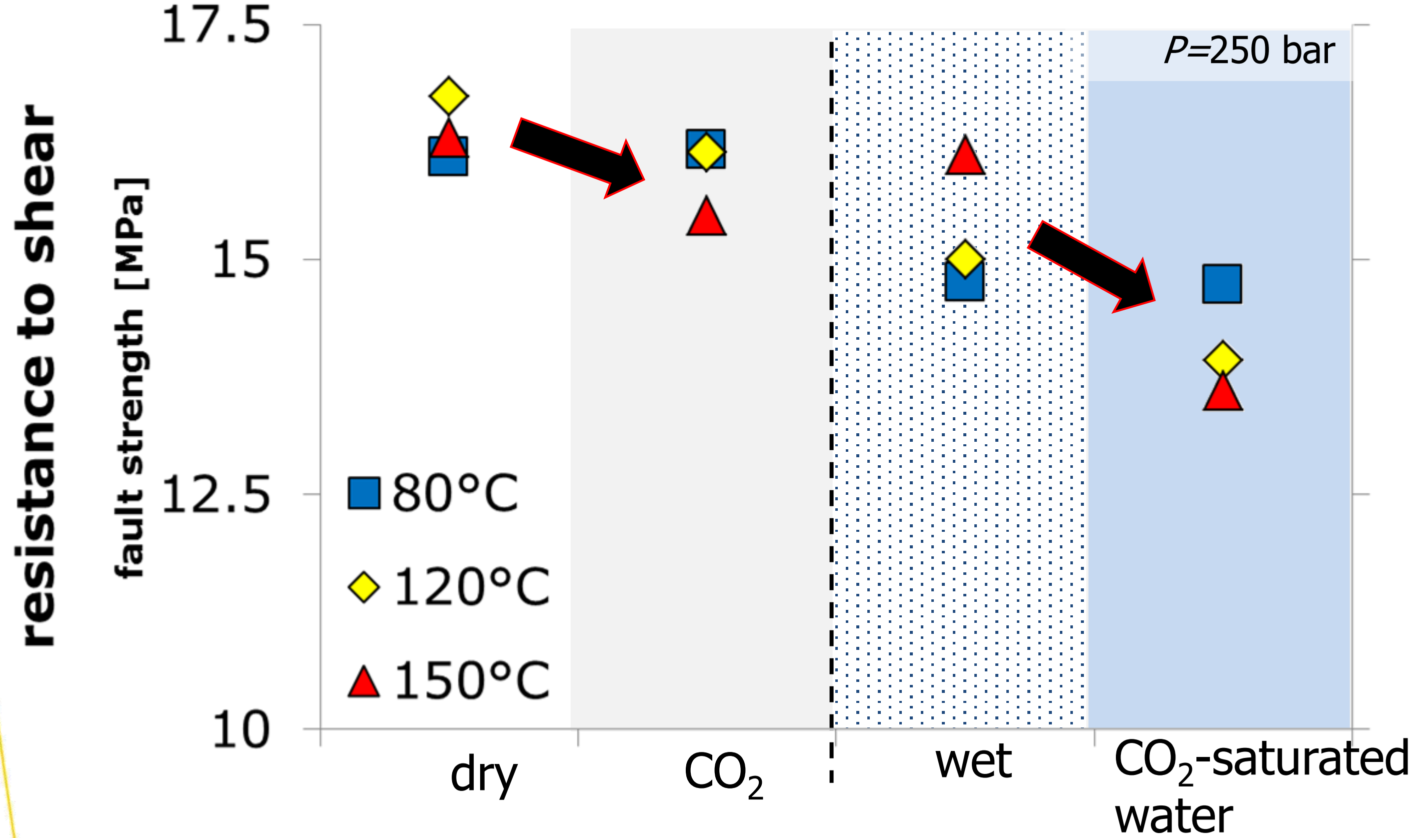


Photo: B. Verberne

Effect of CO_2 on fault strength



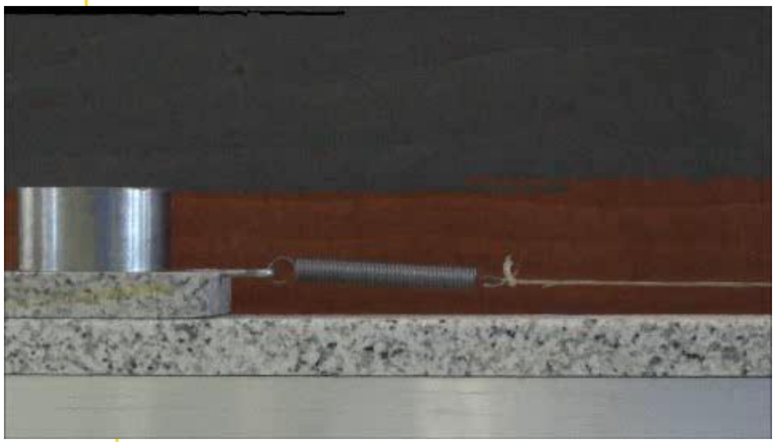
Fault slip becomes easier in the presence of CO_2

- Field management: take weakening into account

Seismicity: spring-slider analogue

Most important condition for a fault zone to be able to host earthquakes:

1) Velocity weakening behaviour (lab tests)



Velocity-weakening interface ➡ Stick-slips (unstable behaviour)

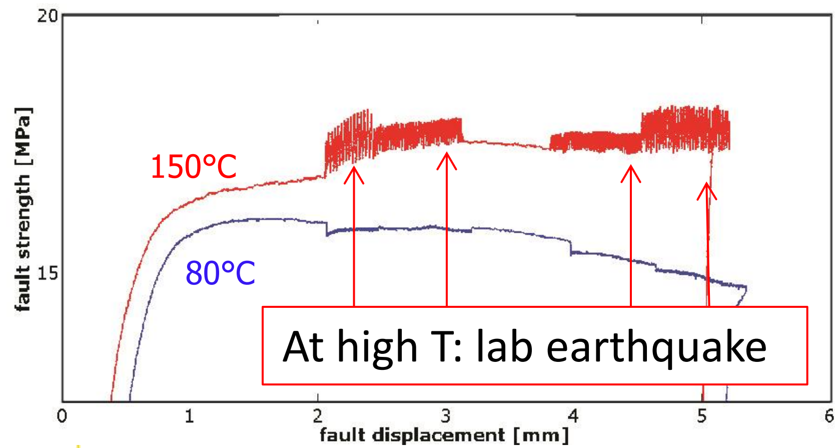
Velocity-strengthening interface ➡ Stable behaviour

Thanks to André Niemeijer for the movies

Can motion in anhydrite-filled faults be (micro-)seismic?

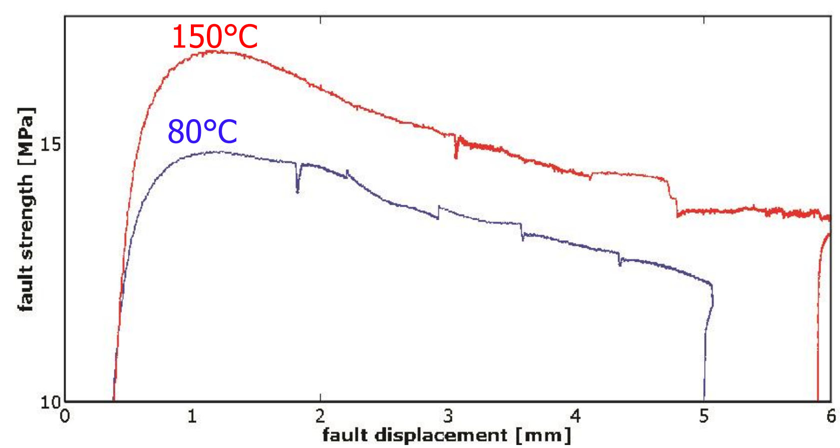
No CO_2

Results of dry experiments



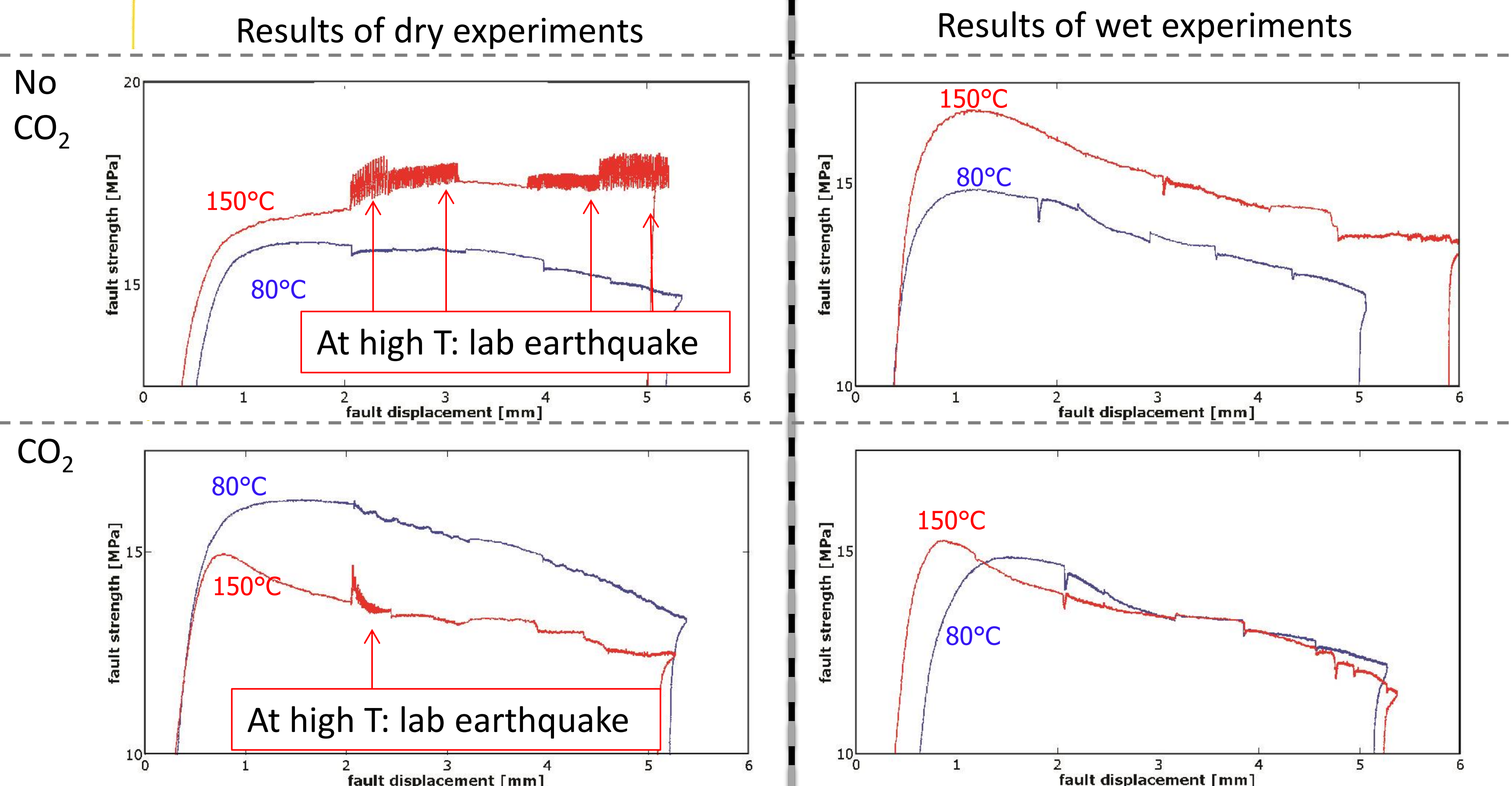
Dry samples:
Unstable behaviour at T≥120°C

Results of wet experiments



Wet samples:
Stable behaviour at all T

Can motion in anhydrite-filled faults be (micro-)seismic?

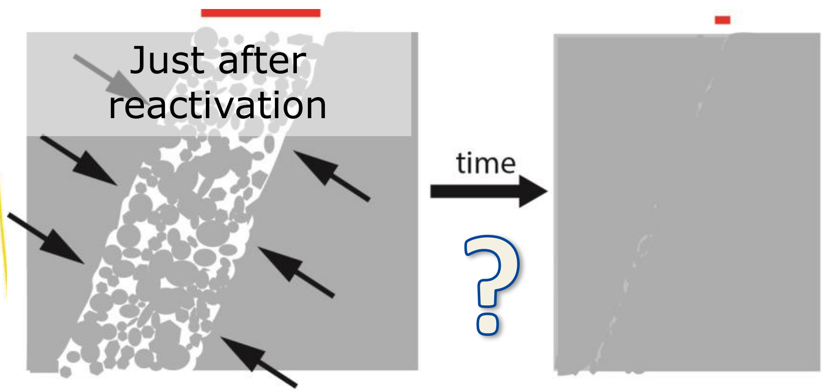


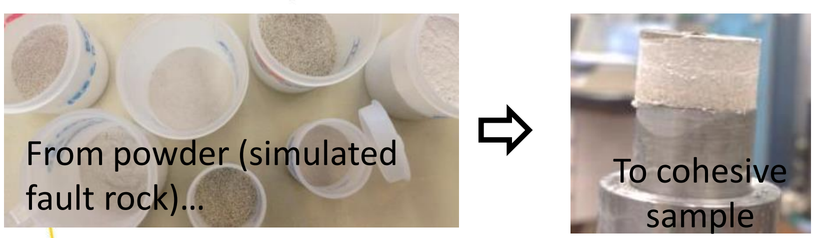
natural faults are wet:
no increased risk on seismicity

Fault sealing: compaction experiments

3) How long will it take a reactivated fault in anhydrite caprock to seal under in situ conditions?

how much time until a reactivated fault is impermeable?



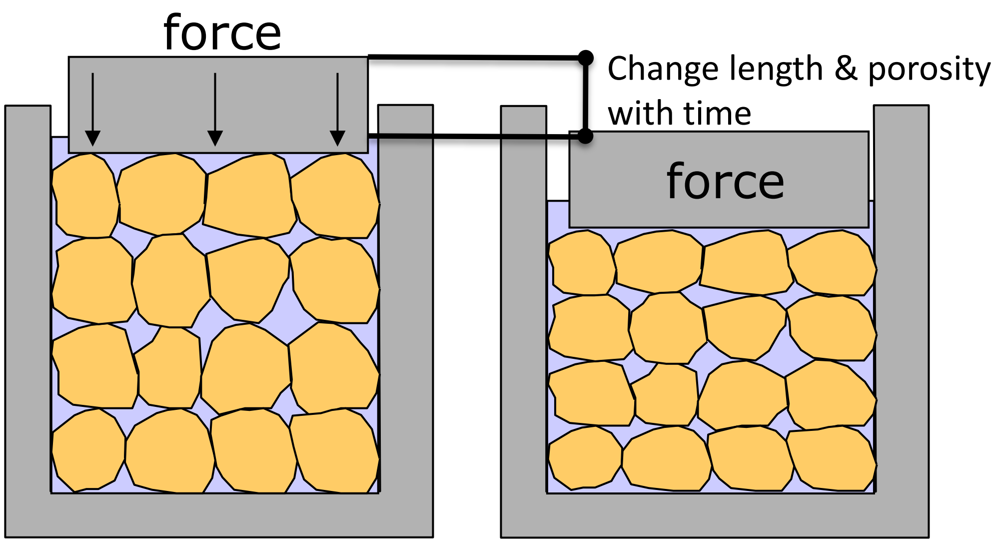


→ **Understanding fault sealing behaviour will help understand leakage risks**

Fault sealing: compaction experiments

3) How long will it take a reactivated fault in anhydrite caprock to seal under in situ conditions?

Compaction experiments:

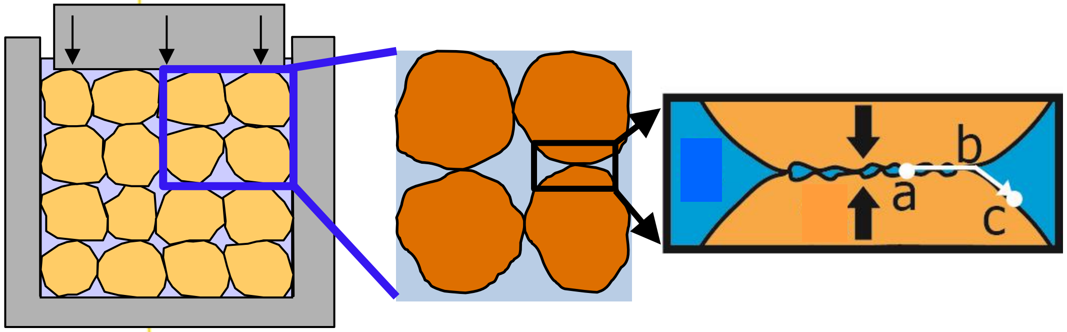


In-situ conditions:
T=80°C, P up to 120 bar

Cartoon: S. Spiers

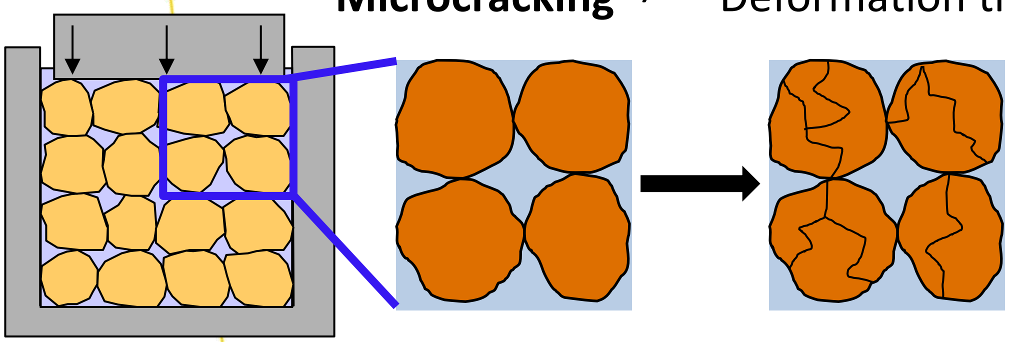
Two main fluid-assisted processes possible at these P-T conditions

Pressure solution [1] Deformation through dissolution and precipitation:



a) Dissolution at stressed grain boundaries
b) Diffusion through the grain boundary fluid
c) Precipitation on (stress-free) pore walls

Microcracking [2] Deformation through breaking of bonds (fracture)



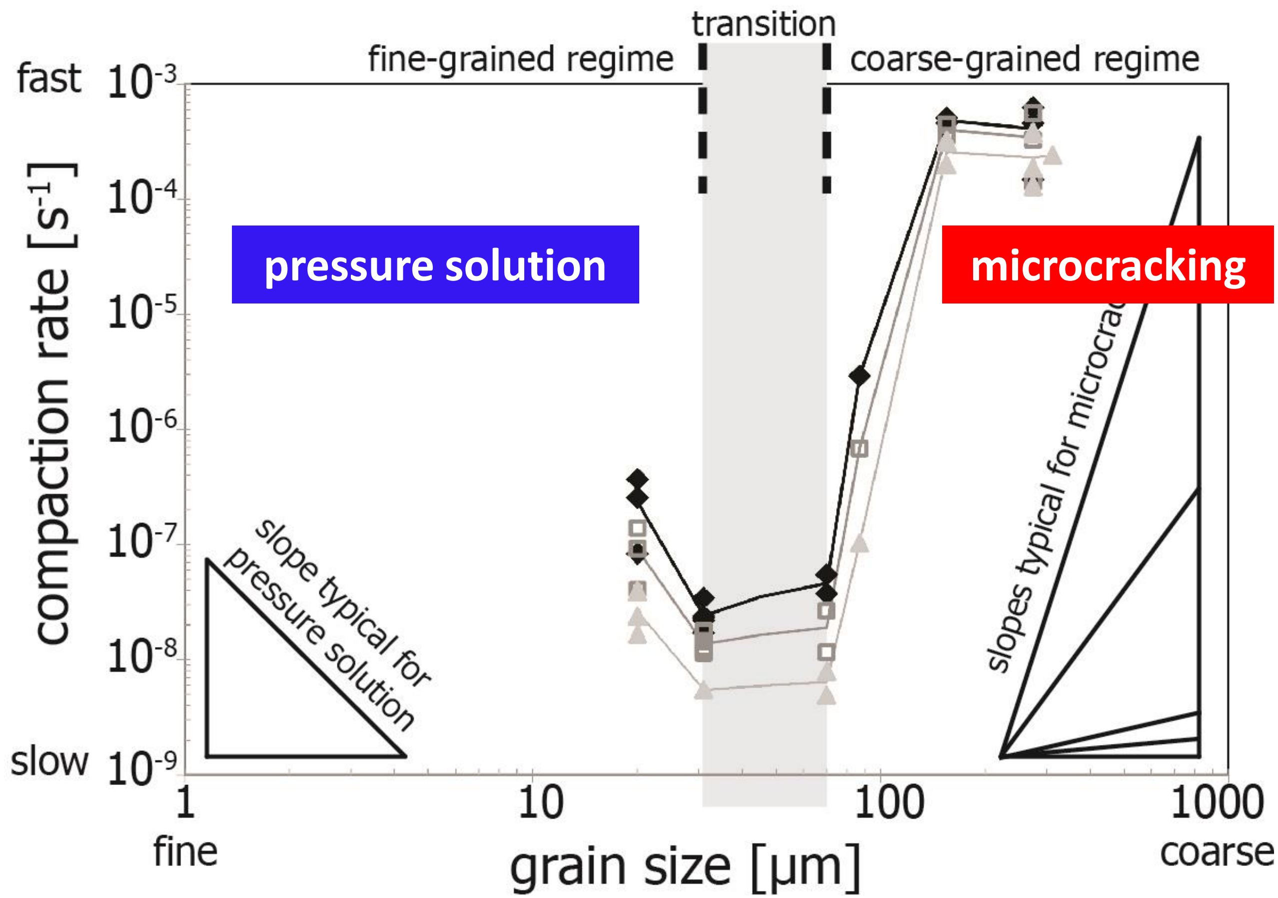
Changes in mineral surface charge (at crack tip):
fluid enhances or inhibits *crack propagation*

1) e.g. Spiers et al, 2004
2) e.g . Atkinson , 1982
3) e.g. De Meer and Spiers, 1997; Zhang et al, 2010
4) e.g. Hangx et al, 2010; Liteanu et al, 2012

Inferred compaction processes in wet anhydrite fault gouge

Deformation mechanism: grain size and stress dependent

Mathematical description based on kinetic theories can be used to interpret experimental results



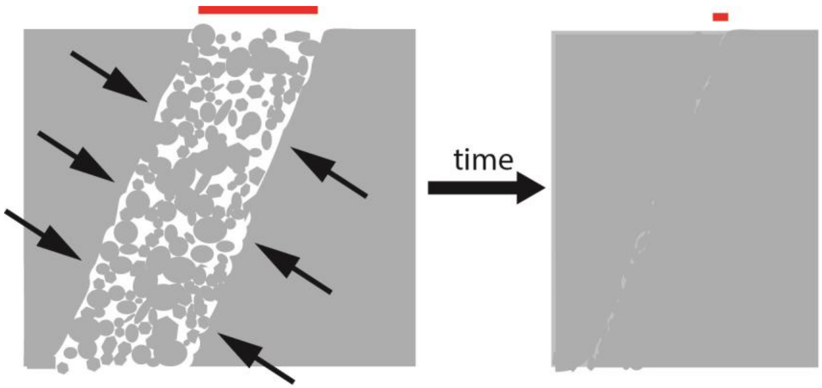
Effect of CO_2 on fault gouge sealing & implications

CO_2 doesn't influence compaction in fine-grained fault gouges

Natural fault gouge will be fine-grained

→ Use a kinetic model[1)] for pressure solution to calculate porosity reduction

10-100 years for fault sealing



[1)] Pluymakers et al, submitted

Conclusions

So… how can we answer our questions?

1) *Does it become easier or more difficult to reactivate a fault in anhydrite when CO_2 is present?*

- Field management: CO_2 leads to ~10% decrease in shear strength

2) If a fault is reactivated, will motion be (micro)seismic?

- For wet anhydrite fault gouge there is no increased risk on micro-seismicity

3) If a fault is reactivated, how long before it is impermeable again?

- Fault sealing is fast: fault sealing only takes tens of years

Thank you

Questions?

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References:

Atkinson, B. K. (1982), Subcritical crack propagation in rocks: theory, experimental results and applications, *Journal of Structural Geology*, *4*(1), 41-56.

De Meer, S., and C. J. Spiers (1997), Uniaxial compaction creep of wet gypsum aggregates, *Journal of Geophysical Research*, *102*(B1), 875-891, doi:10.1029/96jb02481.

Geluk, M. C. (2000), Late Permian (Zechstein) carbonate-facies maps the Netherlands, *Geologie & mijnbouw / Netherlands Journal of Geoscience*, *79*(1), 17-27.

Hangx, S. J. T., C. J. Spiers, and C. J. Peach (2010), Creep of simulated reservoir sands and coupled chemical-mechanical effects of CO2 injection, *Journal of Geophysical Research*, *115*(B9), B09205, doi:10.1029/2009jb006939.

Liteanu, E., A. Niemeijer, C. J. Spiers, C. J. Peach, and J. H. P. De Bresser (2012), The effect of CO2 on creep of wet calcite aggregates, *Journal of Geophysical Research*, *117*(B03211), 20, doi:2011JB008789.

Pluymakers, A. M. H., C. J. Peach, and C. J. Spiers (2014), Diagenetic compaction experiments on simulated anhydrite fault gouge under static conditions, *Submitted*.

Pluymakers, A. M. H., and C. J. Spiers (2014), Compaction creep of simulated anhydrite fault gouge by pressure solution: Theory vs. experiments and implications for fault sealing, *Geological Society, London, Special Publications*.

Quattrocchi, F., B. Cantucci, D. Cinti, G. Galli, L. Pizzino, A. Sciarra, and N. Voltattorni (2009), Continuous/discrete geochemical monitoring of CO2 Natural Analogues and of Diffuse Degassing Structures (DDS): hints for CO2 storage sites geochemical monitoring protocol, *Energy Procedia*, *1*, 2135-2142.

Spiers, C. J., S. De Meer, A. R. Niemeijer, and X. Zhang (2004), Kinetics of rock deformation by pressure solution and the role of thin aqueous films, in *Physicochemistry of water in geological and biological systems - structures and properties of thin aqueous films*, edited by S. Nakashima, C. J. Spiers, L. Mercury, P. A. Fenter and M. F. Hochella, Jr., pp. 129-158, Universal Academy Press, Inc. , Tokyo.

Voltattorni, N., A. Sciarra, G. Caramanna, D. Cinti, L. Pizzino, and F. Quattrocchi (2009), Gas geochemistry of natural analogues for the studies of geological CO2 sequestration, *Applied Geochemistry*, *24*, 1339-1346.

Zhang, X., C. J. Spiers, and C. J. Peach (2010), Compaction creep of wet granular calcite by pressure solution at 28°C to 150°C, *Journal of Geophysical Research*, *115*(B9), B09217, doi:10.1029/2008jb005853

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