Induced Seismicity in Geo-energies



idaea
INSTITUT DE DIAGNOSI AMBIENTAL I ESTUDIS DE L'AIGUA

Víctor Vilarrasa
(victor.vilarrasa@idaea.csic.es)

CSIC
CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

Jesus Carrera, Sebastià Olivella, Jonny Rutqvist and Lyesse Laloui

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Why we care about it

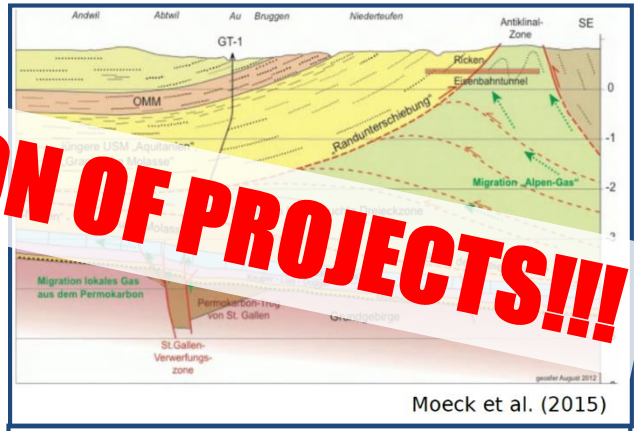
The interest in **subsurface energy** resources has significantly increased as a means to mitigate climate change…

…inducing numerous cases of **felt seismicity**

Basel (Switzerland) 2006, M3.4

Castor (Spain) 2013, M4.2

LEADING TO THE CANCELLATION OF PROJECTS!!!



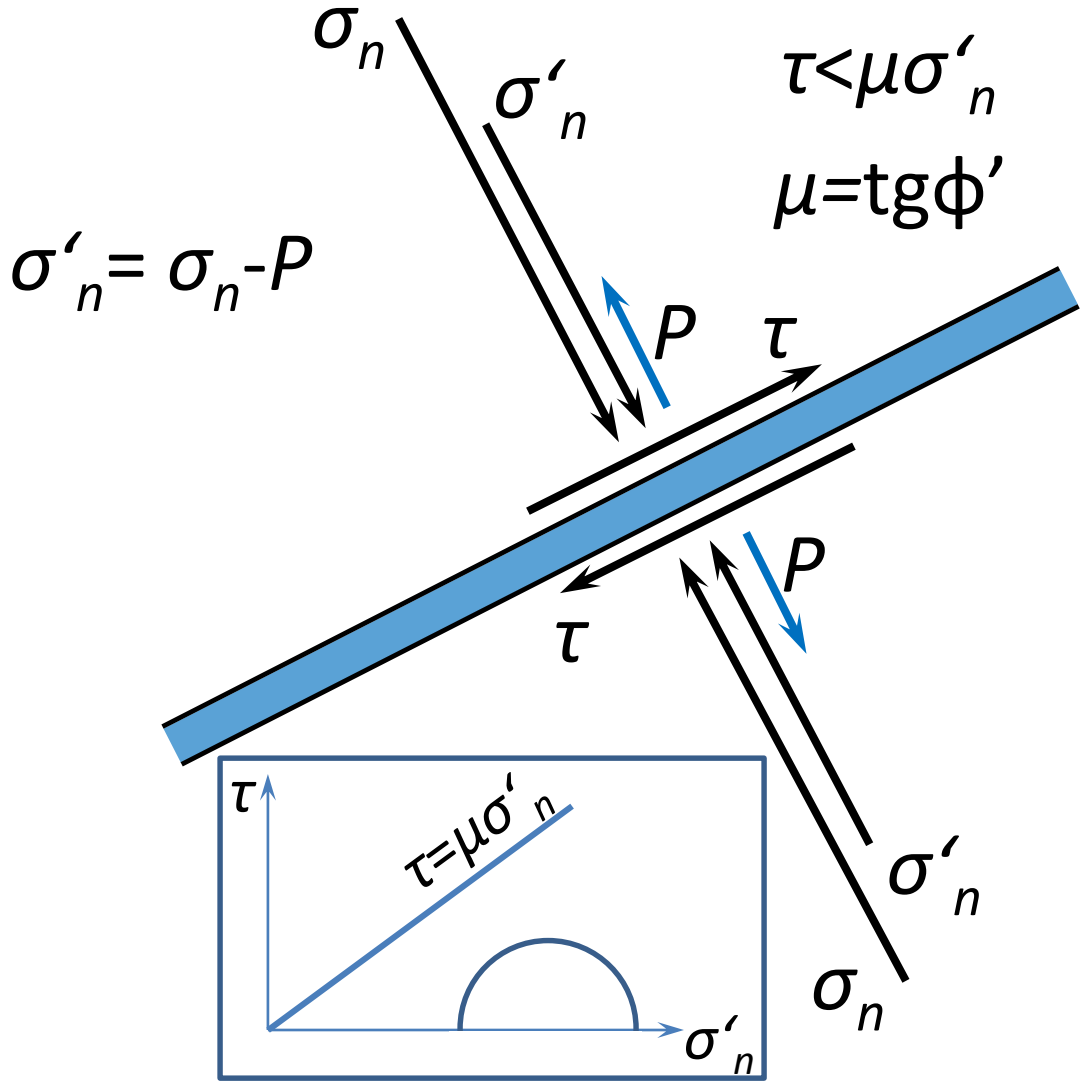
Moeck et al. (2015)

Sankt Gallen (Switzerland) 2013, M3.3

Oklahoma (US) 2011, M5.6
2016, M5.8

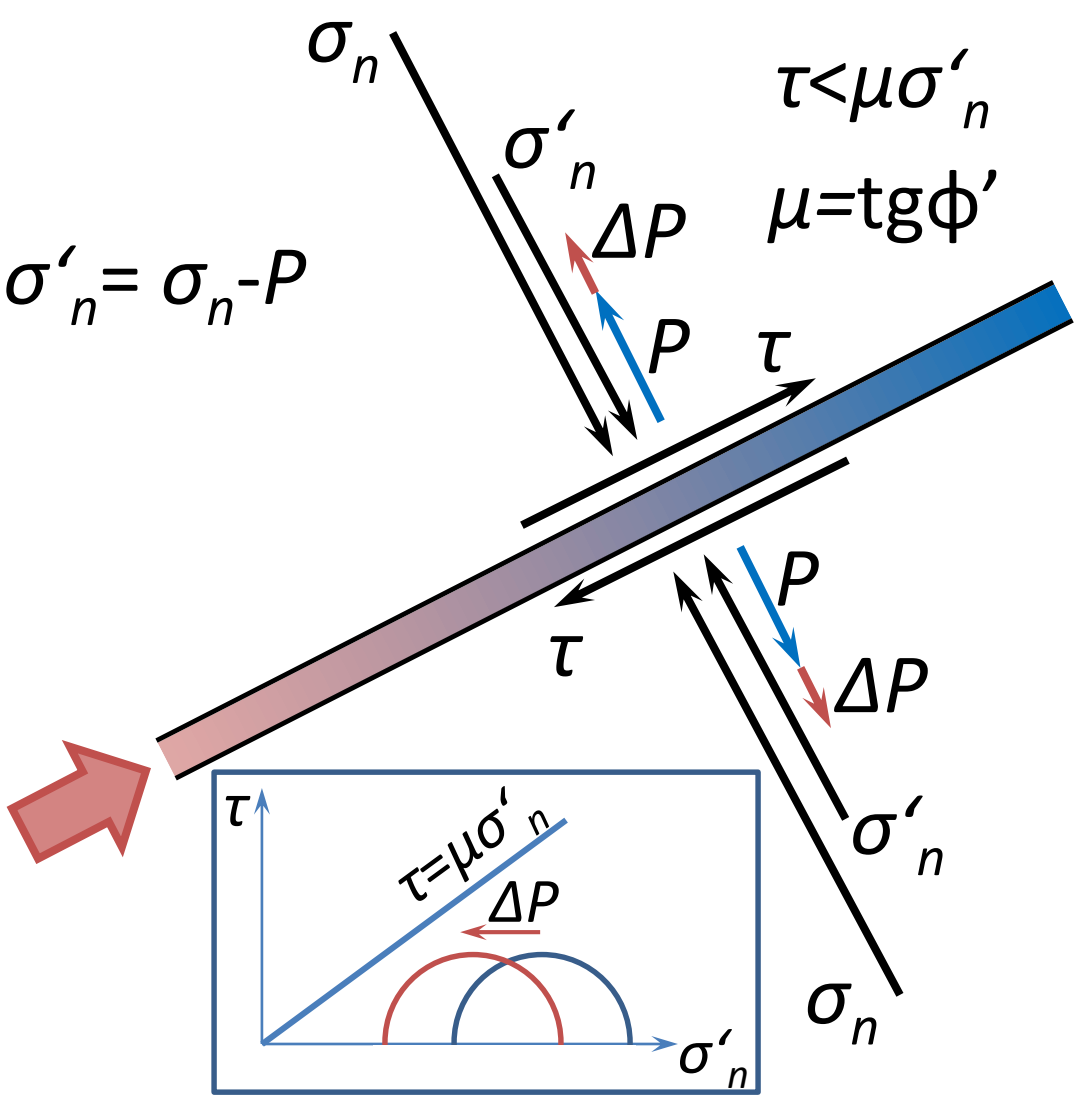
What induces seismicity

Geo-energies imply **fluid injection** in the subsurface



A fracture is stable while tangential forces (τ) are lower than the friction coefficient (μ) multiplied by the fracture normal effective stress (σ'_n)

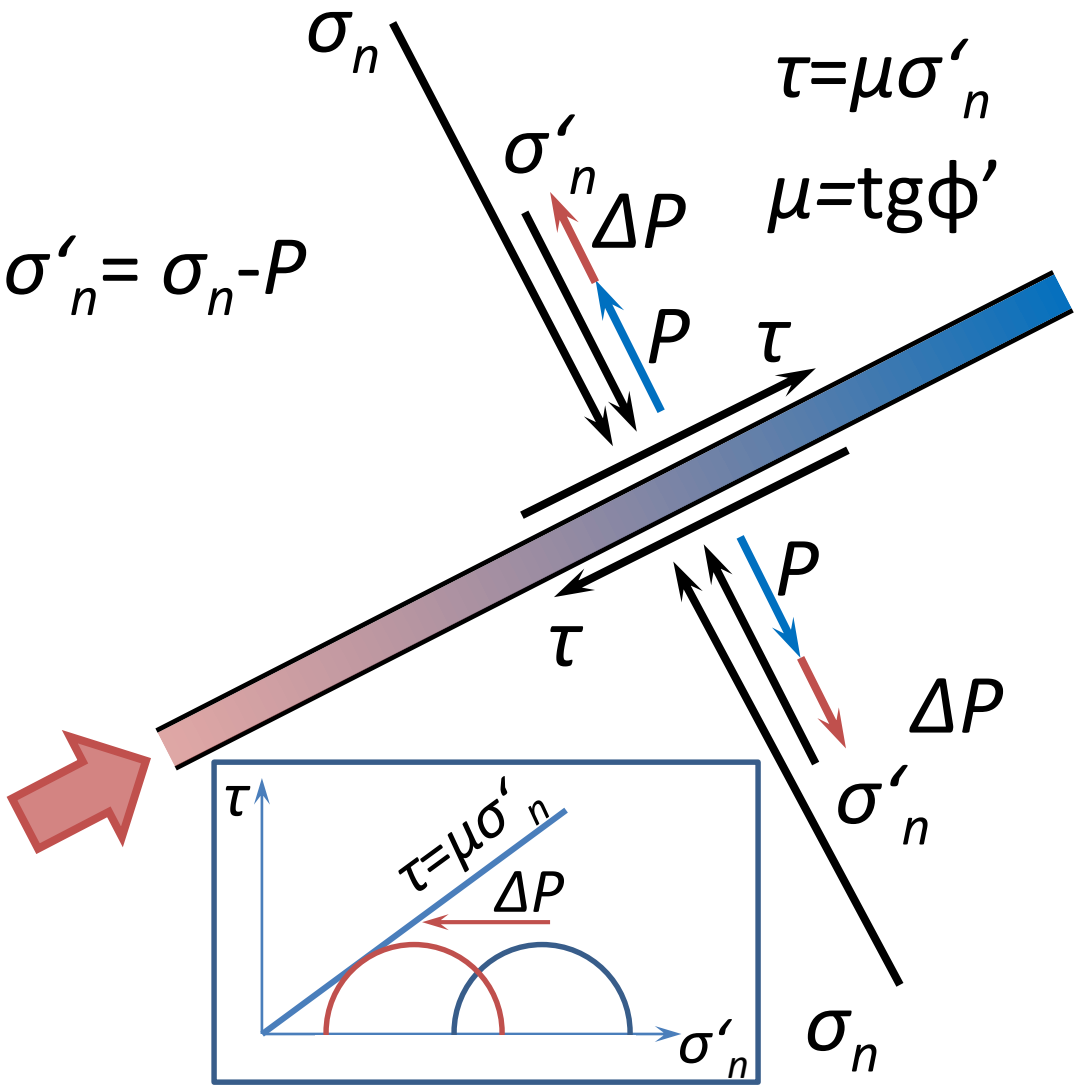
What induces seismicity



Fluid injection produces a pore pressure increase (ΔP) inducing fluid flow through the fracture.

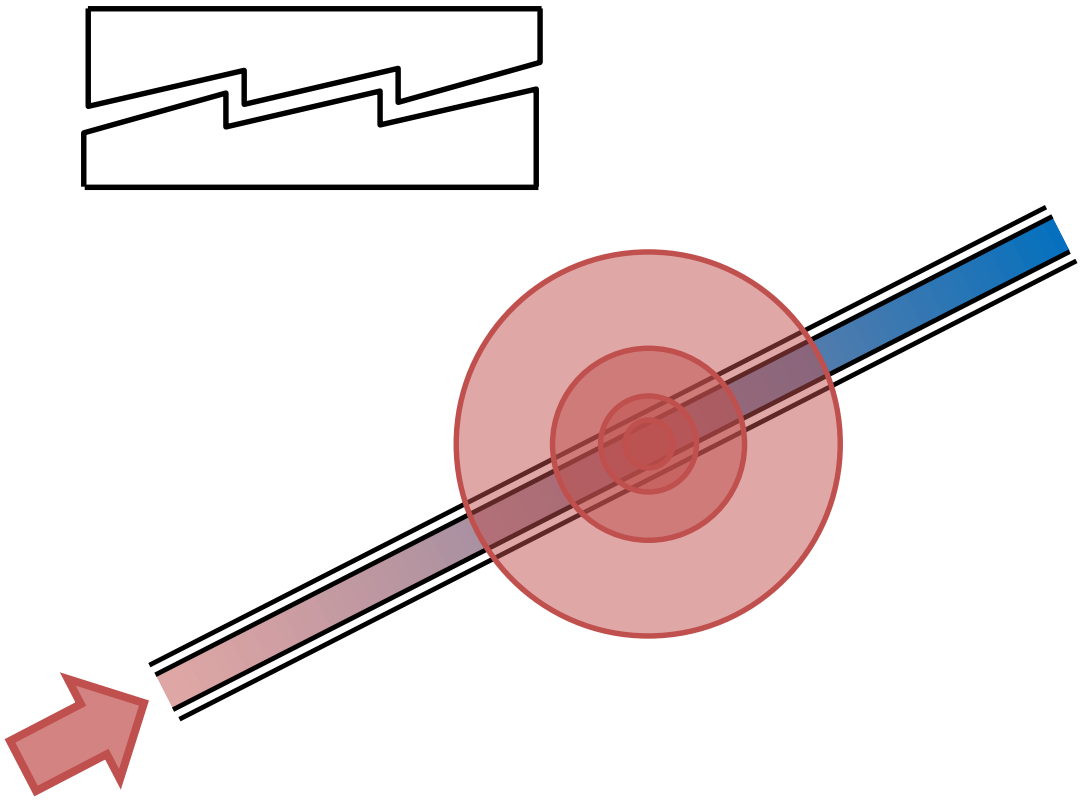
This overpressure (ΔP) opposes to the normal stress that tends to close the fracture, reducing the effective stress

What induces seismicity



If the overpressure (ΔP) is high enough ($\tau=\mu\sigma'_n$), shear slip occurs between the planes of the fracture

What induces seismicity



Sliding will open the fracture and trigger a microseismic event.

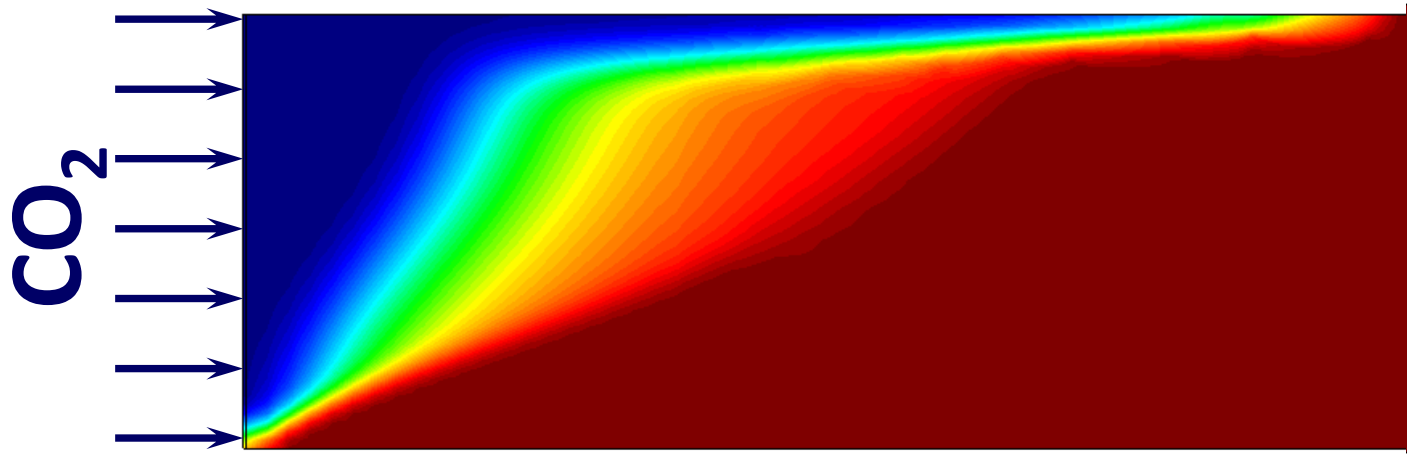
Fracture opening in the aquifer can enhance injectivity, but it may open up migration paths in the caprock.

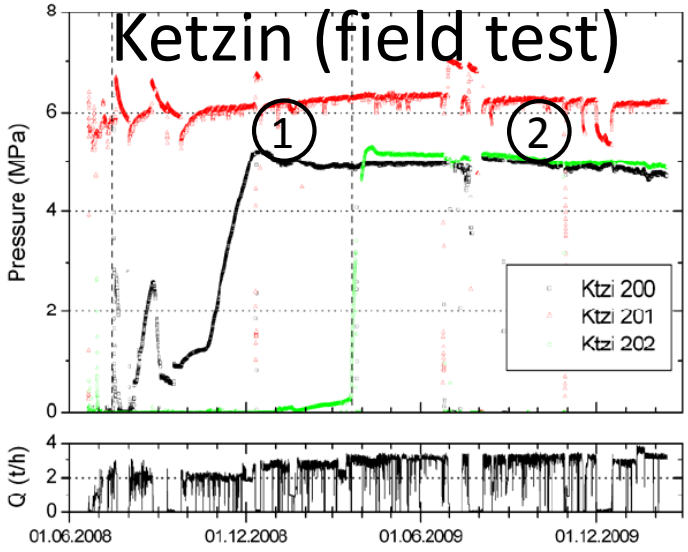
Vilarrasa *et al*. (2011) *TIPM*

In theory, the triggering mechanism is simple, so we should be able to control it. But…

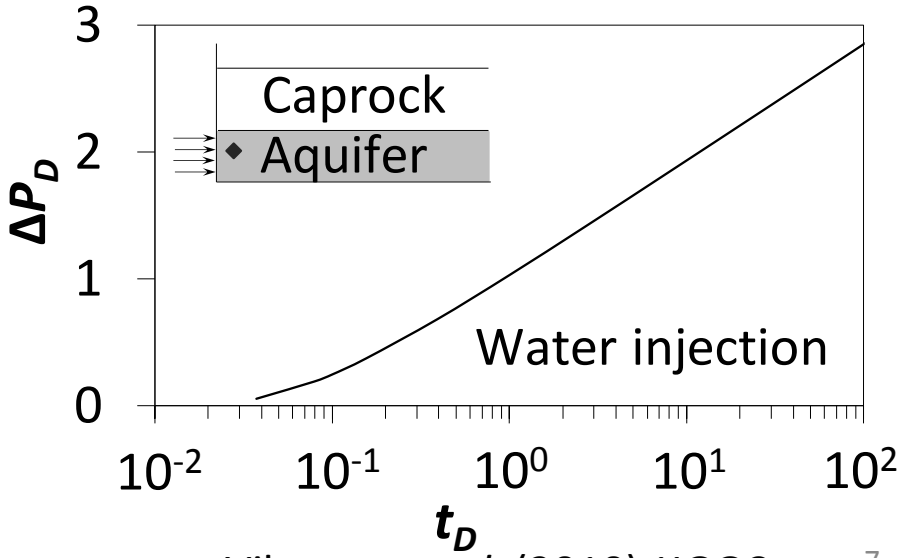
Pressure evolution

Geologic carbon storage (GCS)





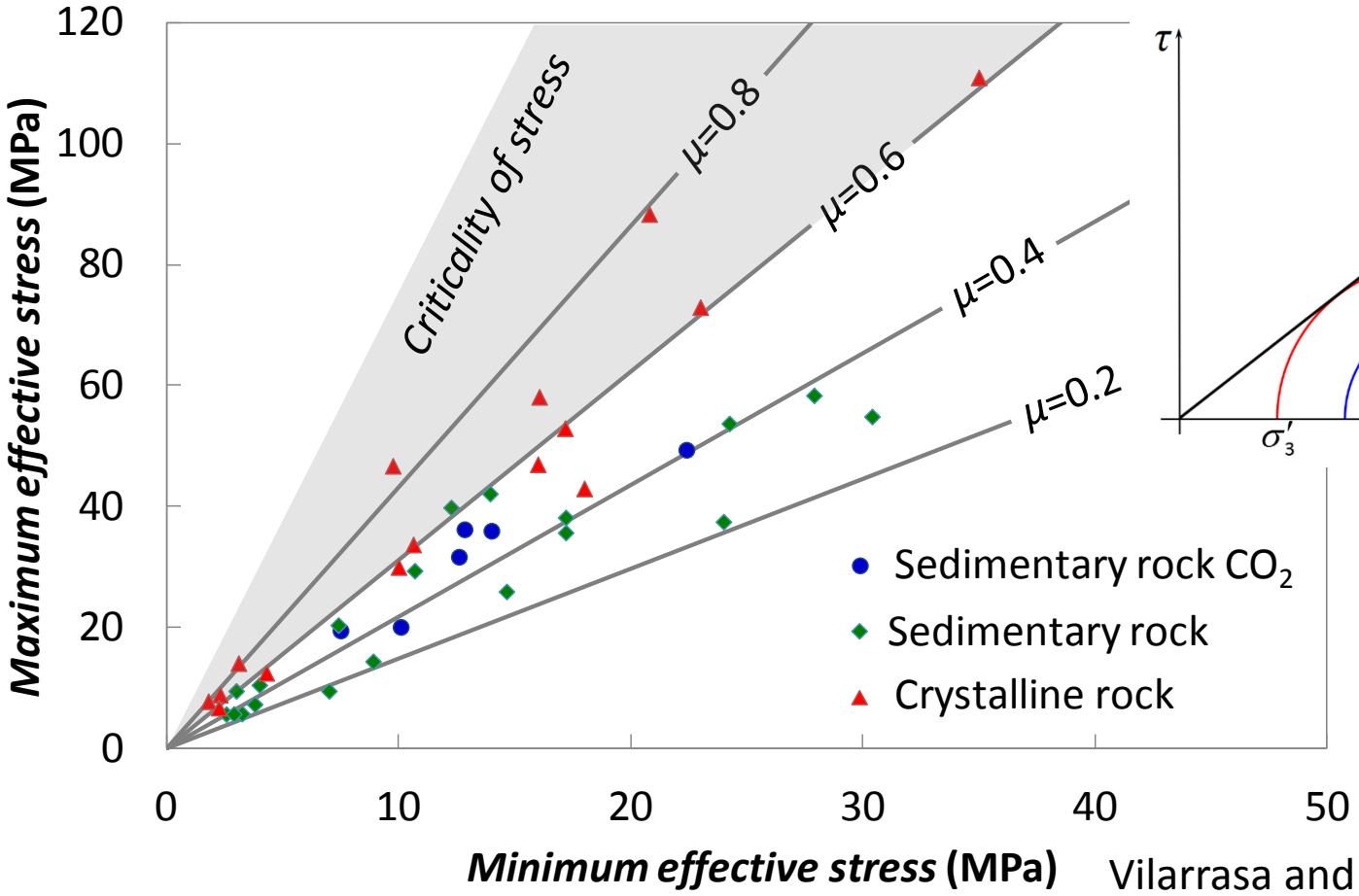
Henninges *et al*. (2011)

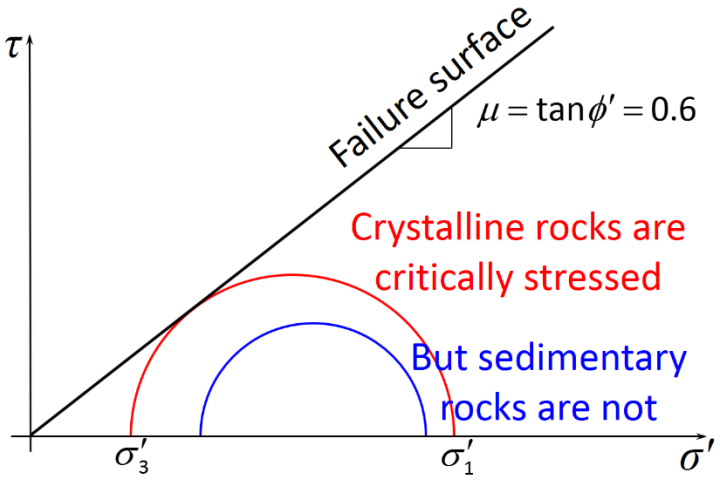


Vilarrasa *et al*. (2010) *IJGGC*

Stress state

While the crystalline basement is critically stressed, sedimentary rocks are generally not, so there is margin to increase fluid pressure safely

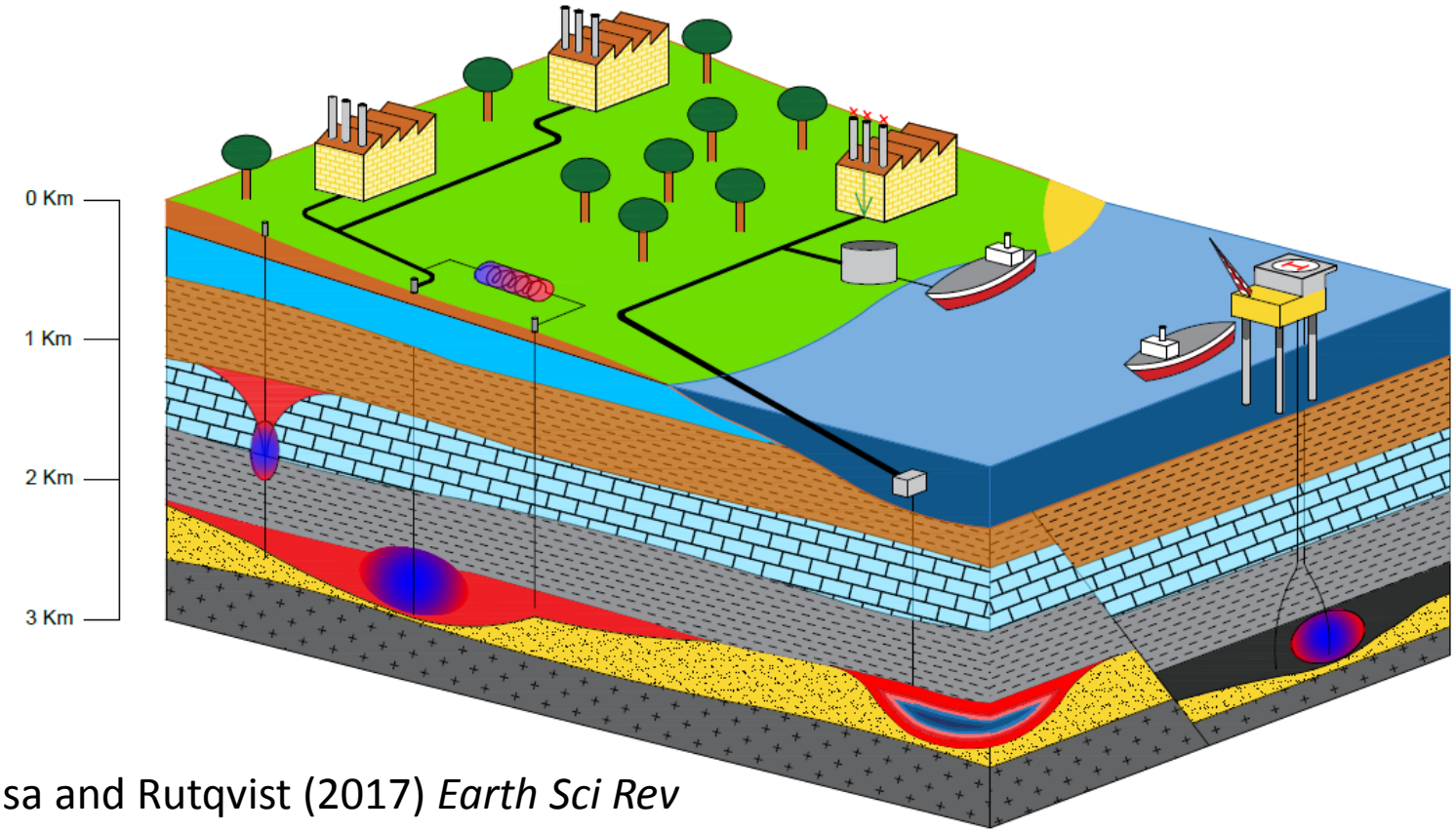




Vilarrasa and Carrera (2015) *PNAS*

Thermal effects

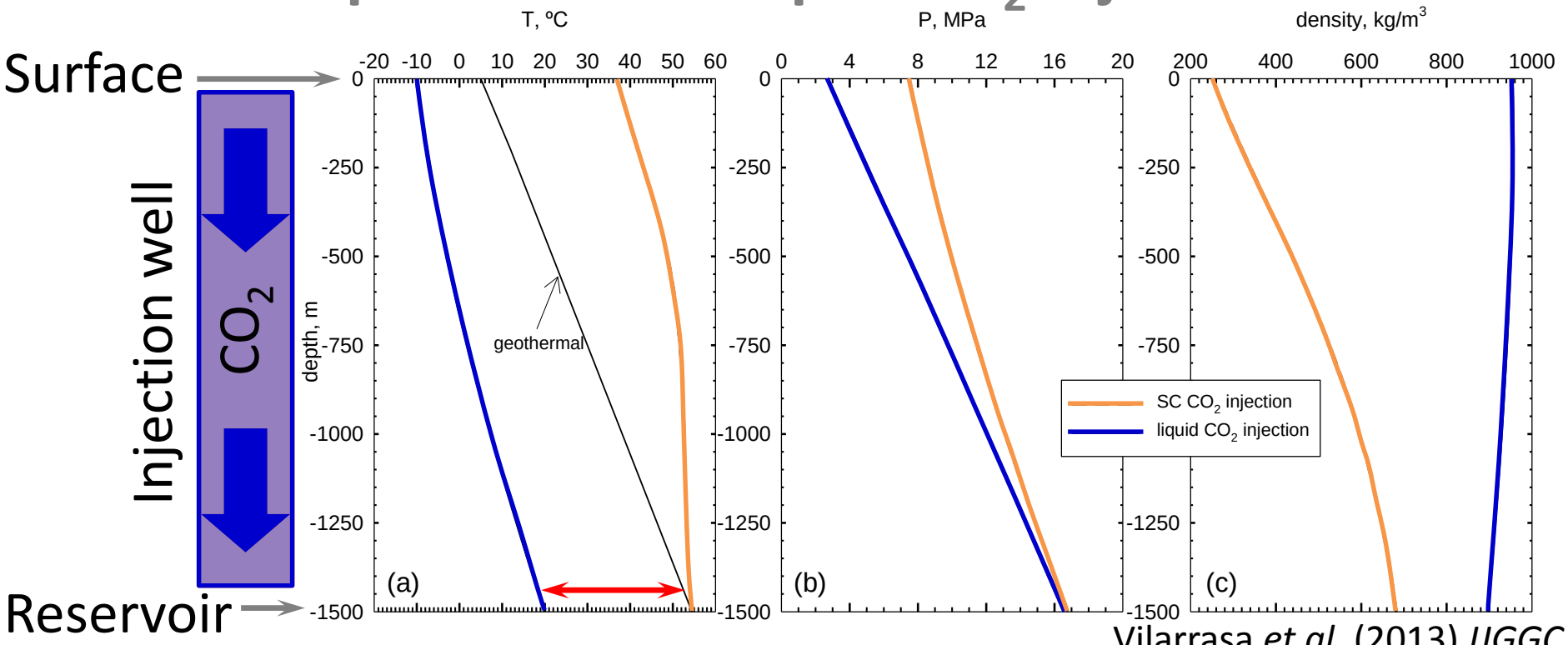
The whole CCS chain needs to be taken into account. The optimal conditions for CO_2 transport are in liquid state. Why don't we take advantage of this?



Vilarrasa and Rutqvist (2017) *Earth Sci Rev*

Liquid CO_2 injection

Supercritical vs liquid CO_2 injection



Vilarrasa *et al*. (2013) *IJGGC*

Compression energy (1Mt/yr)

Supercritical CO_2 $69.3 \cdot 10^6$ kWh

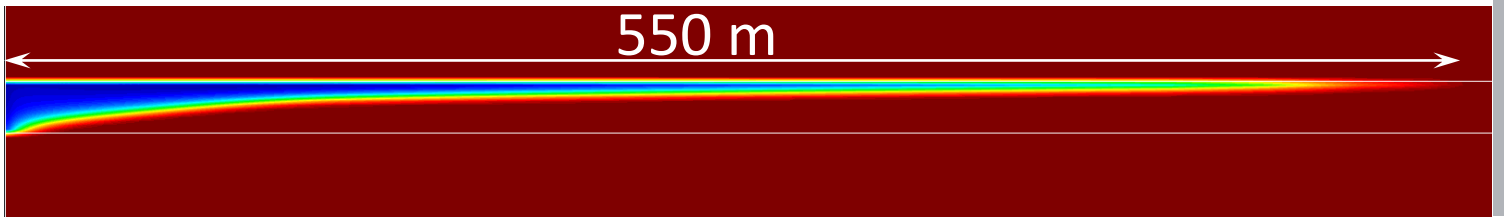
Liquid CO_2 $5.9 \cdot 10^6$ kWh

$$\downarrow \Delta T \Rightarrow \downarrow \Delta \sigma'$$

Induced microseismicity? Hydraulic fracturing of caprock?

Caprock integrity is maintained…

Inelastic strain is restricted to the cold region inside the reservoir and does not propagate into the caprock



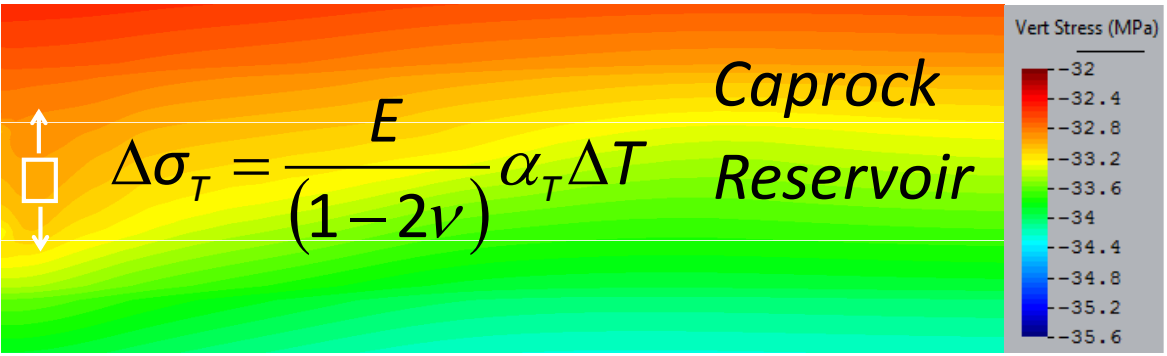
Cooling front advances much behind of CO_2 plume front

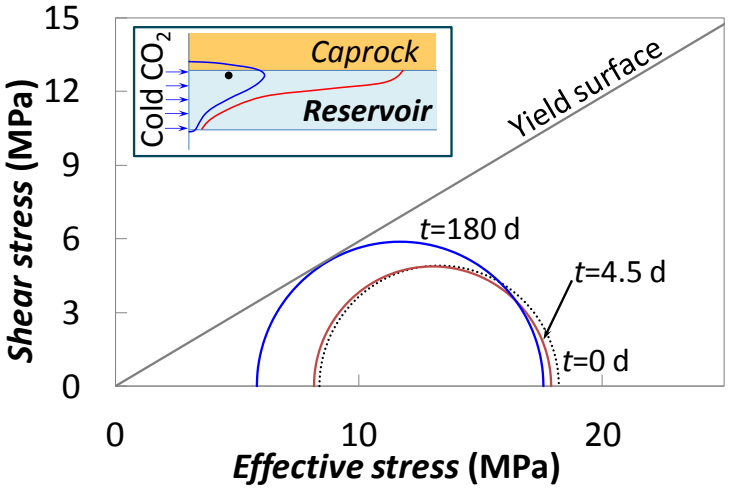
Fractures open up in reservoir: increased permeability!

Fractures do not propagate into the caprock!

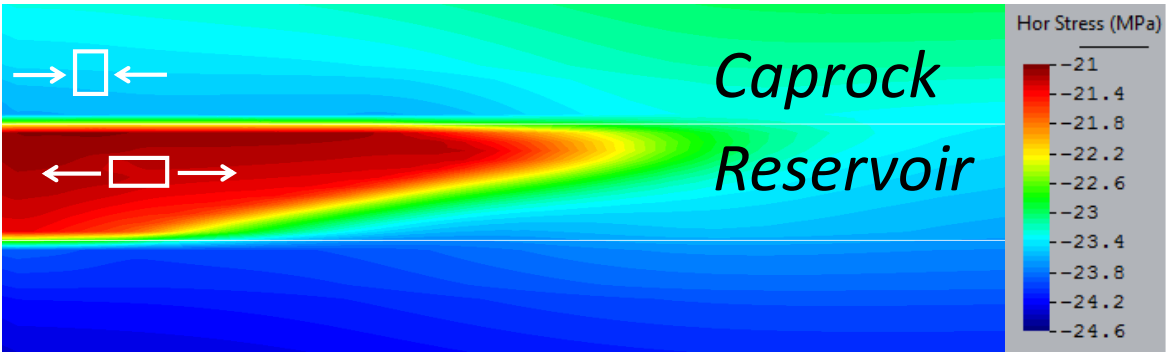
…due to stress redistribution

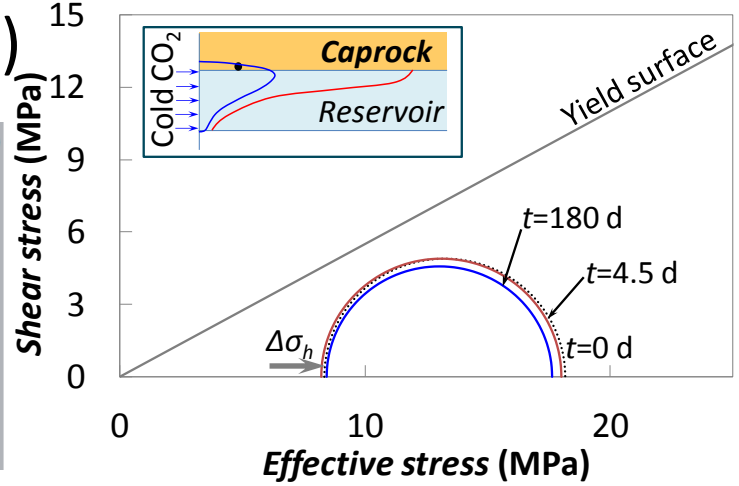
Contraction induces a thermal stress reduction in all directions, including the vertical





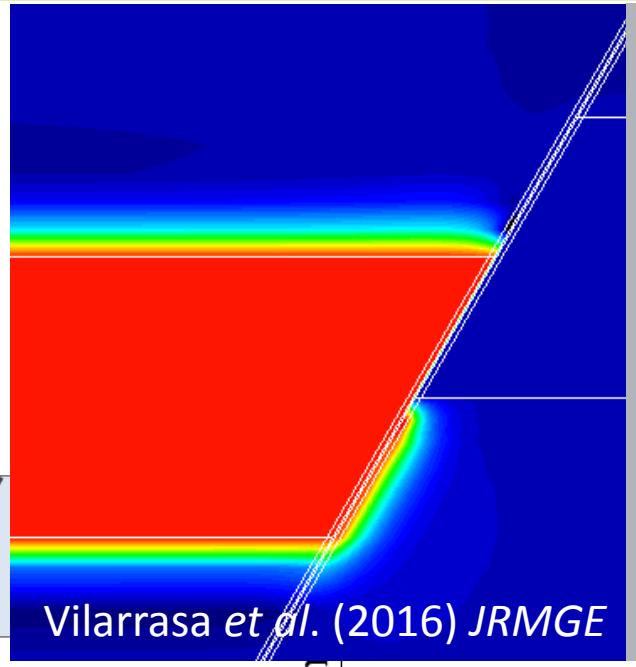
This causes a stress redistribution to satisfy stress equilibrium and displacement compatibility that tightens the lower portion of the caprock (**caprock integrity is maintained**)

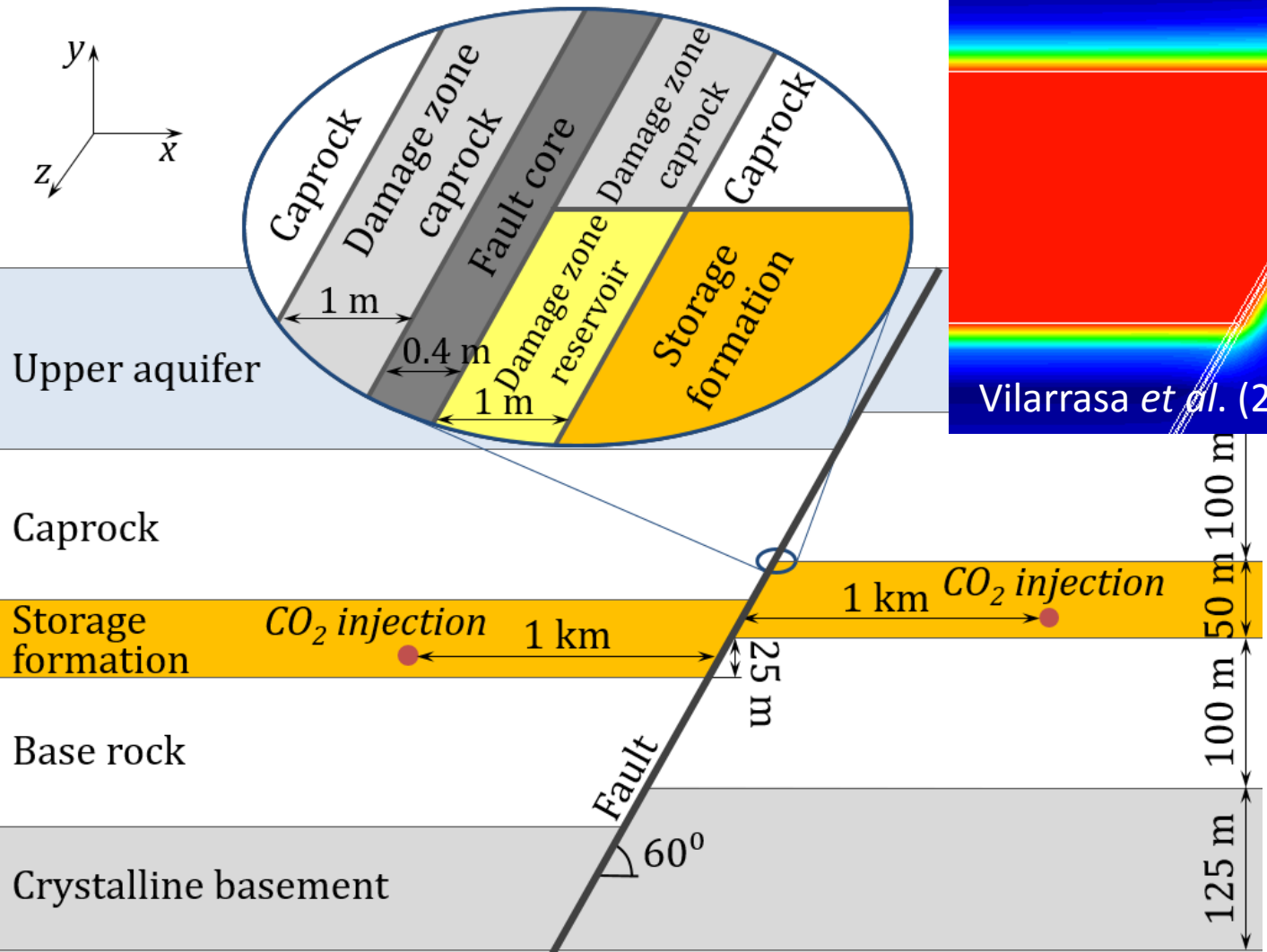




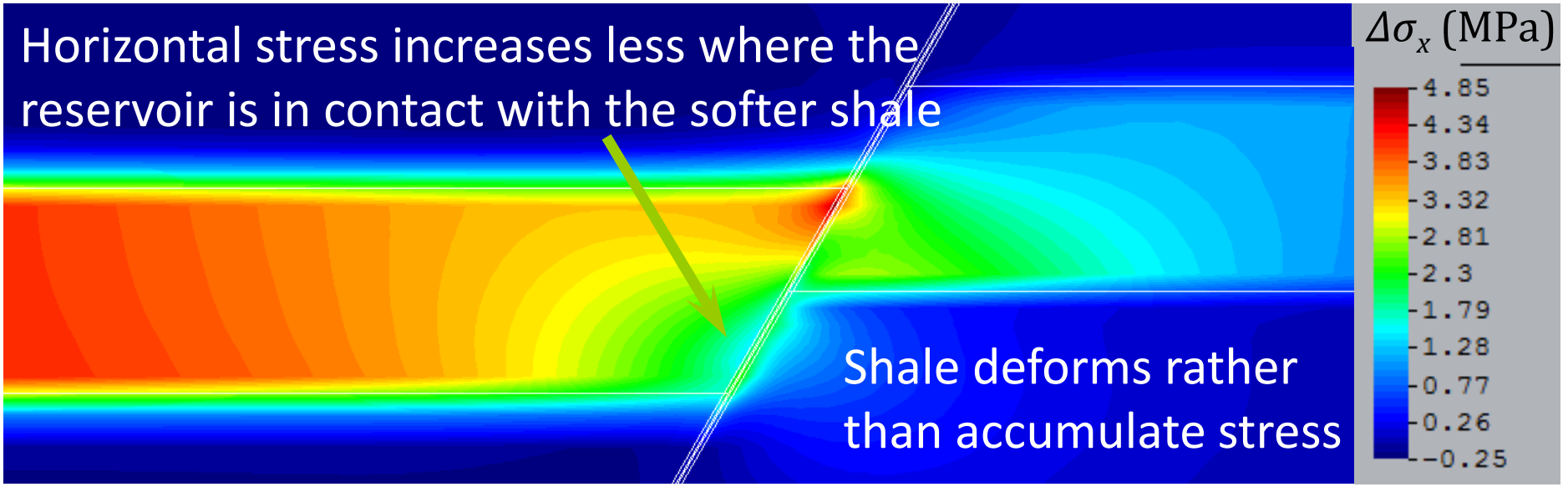
But if faults are present…

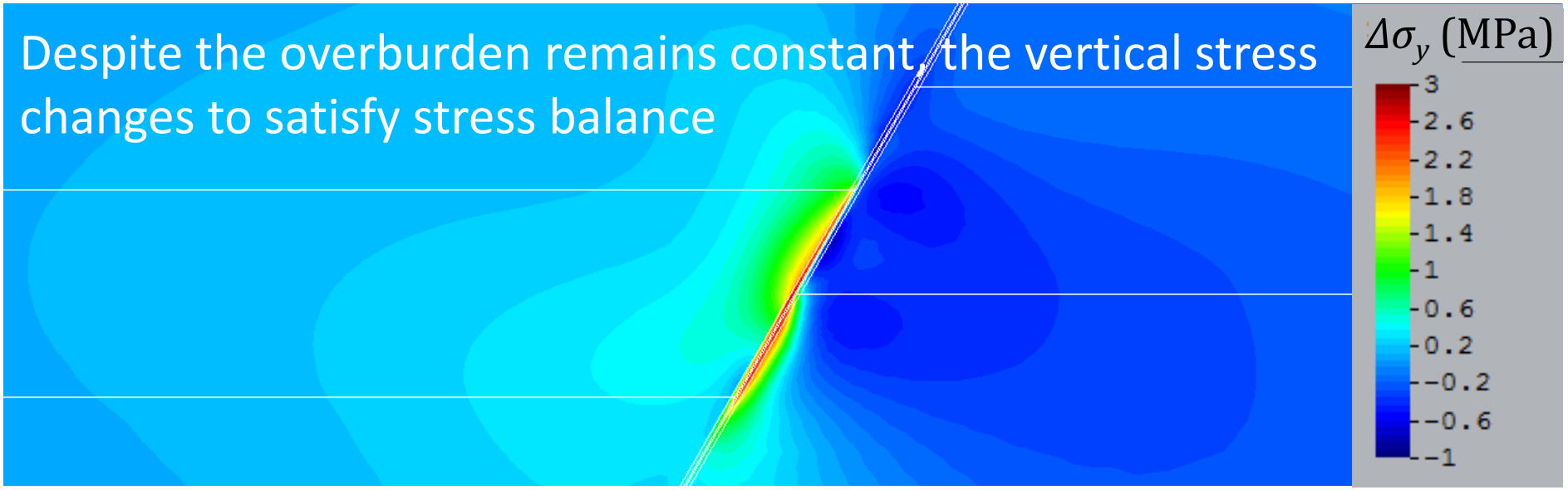
…the additional overpressure may compromise fault and caprock stability



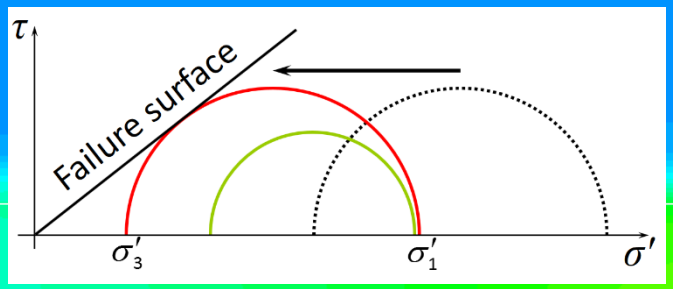


Stress changes around the fault





Low-k faults may be reactivated



Since horizontal stress does not increase in the lower half of the reservoir, the deviatoric stress is maintained, becoming the most critical zone

$\Delta\phi_{mob}$ (°)
31.7
27.53
23.36
19.19
15.02
10.85
6.68
2.51
-1.66
-5.83
-10

k=10^{-19} m^2

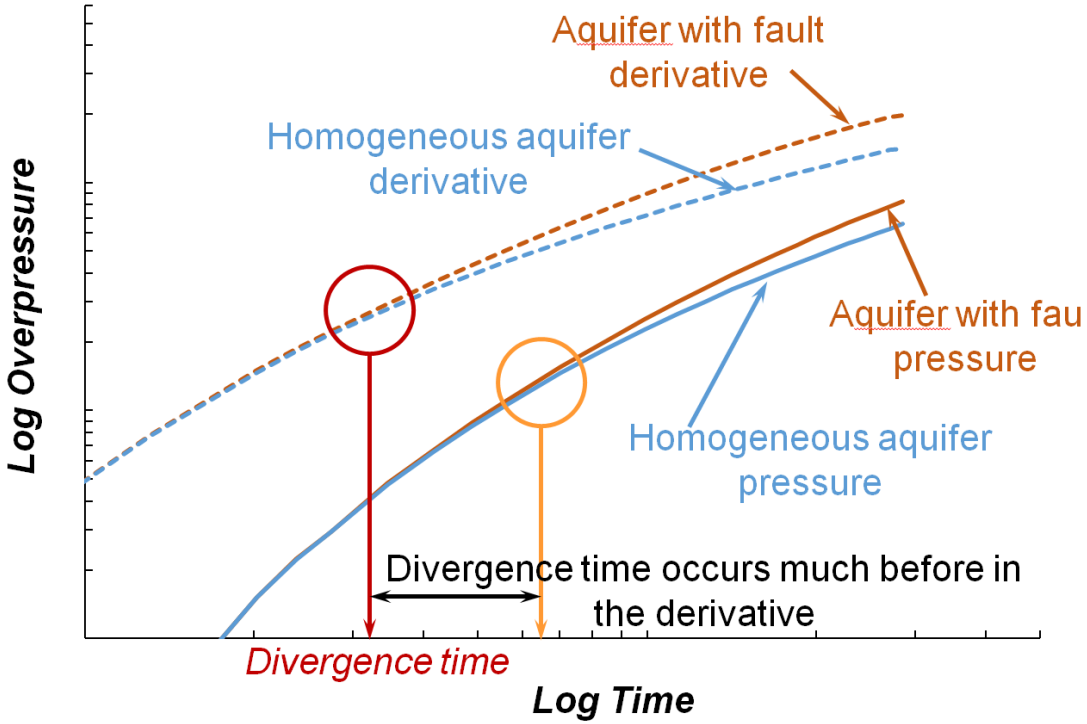
The fault would be reactivated in the lower half of the reservoir if no pressure management is performed (only for low-permeable faults k<10^{-17} m^2)

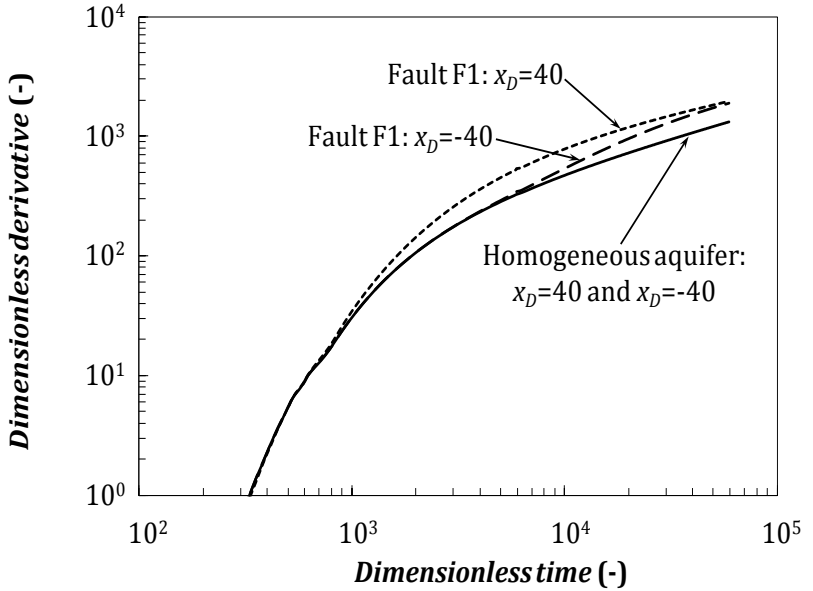
$\Delta\phi_{mob}$ (°)
31.7
27.53
23.36
19.19
15.02
10.85
6.68
2.51
-1.66
-5.83
-10

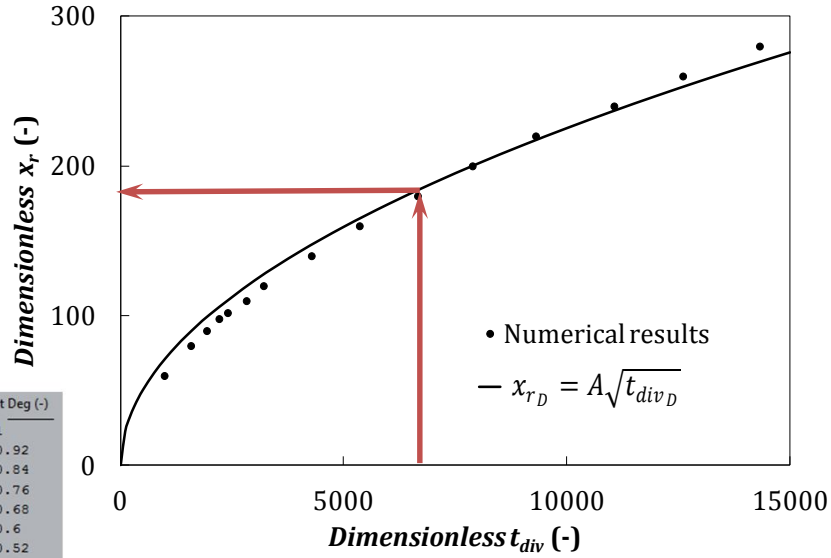
k=10^{-17} m^2

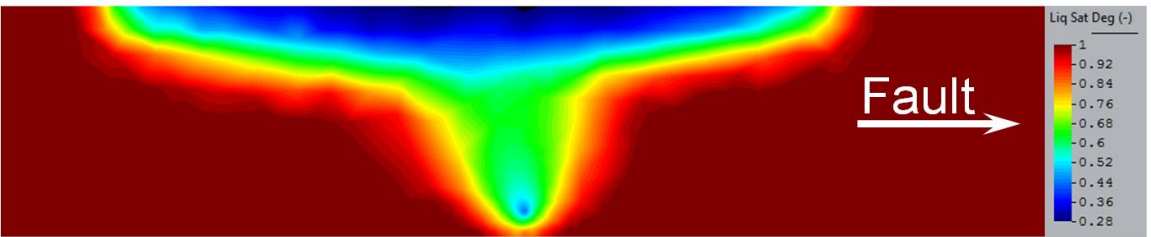
What can we do?

Low-permeable faults can be identified and located by analyzing fluid pressure evolution using diagnostic plots



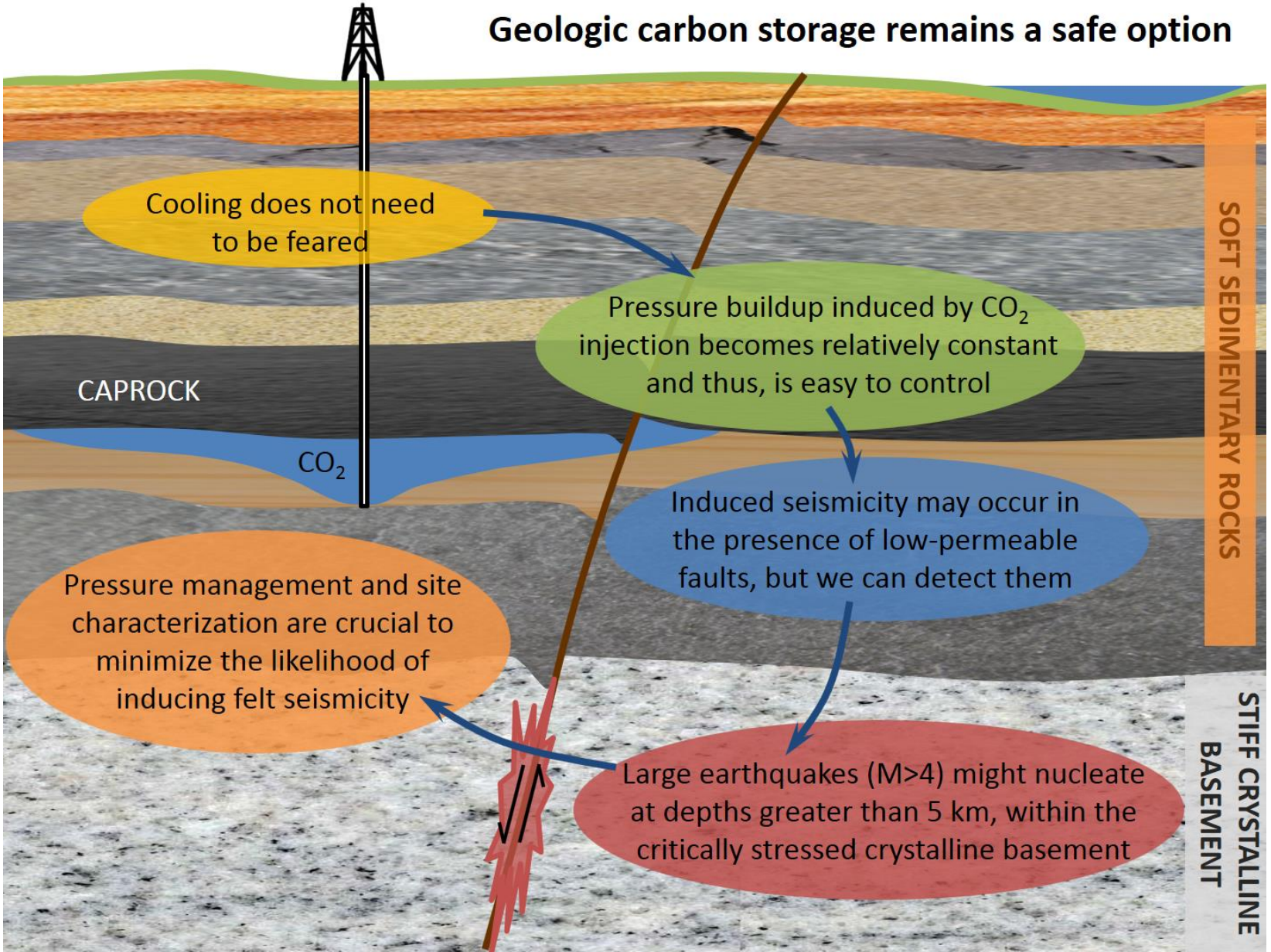






Vilarrasa *et al.* (2017) *IJGGC*

Take-home message



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QUESTIONS?

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