Is fault width evolution in induced seismicity analogous to that of natural seismicity?

Víctor Vilarrasa
victor.vilarrasa@idaea.csic.es

Seminar Hydrogeology Journal Editors, Barcelona, 5 April, 2019
We need to reach zero emissions by 2050 to meet the Paris Agreement goal of limiting temperature increase to 2°C.

$\text{CO}_2$ makes us fatter: orexins (hormones) increase our appetite.
All scenarios coincide in the need for geologic carbon storage (GCS) to reach zero emissions.

According to the IEA, we should inject **8 Gt CO$_2$/yr by 2050**, so we will need in the order of **8,000 storage projects**.
It has been claimed that GCS will induce large earthquakes, but our research shows that it can be done safely.
Can CO\textsubscript{2} injection actually induce large earthquakes?

<table>
<thead>
<tr>
<th>Material</th>
<th>Permeability (m\textsuperscript{2})</th>
<th>Porosity (-)</th>
<th>Entry pressure (MPa)</th>
<th>Young's modulus (GPa)</th>
<th>Poisson ratio (-)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Storage formation</td>
<td>$4 \cdot 10^{-14}$</td>
<td>0.23</td>
<td>0.02</td>
<td>14.0</td>
<td>0.31</td>
</tr>
<tr>
<td>Damage zone reservoir</td>
<td>$2 \cdot 10^{-13}$</td>
<td>0.25</td>
<td>0.02</td>
<td>7.0</td>
<td>0.35</td>
</tr>
<tr>
<td>Shale</td>
<td>$8 \cdot 10^{-20}$</td>
<td>0.05</td>
<td>10.0</td>
<td>3.0</td>
<td>0.40</td>
</tr>
<tr>
<td>Damage zone shale</td>
<td>$1.5 \cdot 10^{-19}$</td>
<td>0.09</td>
<td>5.0</td>
<td>1.4</td>
<td>0.42</td>
</tr>
<tr>
<td>Fault core</td>
<td>$1 \cdot 10^{-19}$</td>
<td>0.10</td>
<td>4.0</td>
<td>1.0</td>
<td>0.30</td>
</tr>
</tbody>
</table>

Vilarrasa et al. (2016) *JRMGE*
The CO$_2$ plume evolution is affected by the presence of the low-permeable fault, tending to migrate away from it.
The low-permeability of the fault leads to a high pressure buildup if no pressure management is performed.
There is an inhomogeneous response of the stresses to reservoir pressurization due to the stiffness contrast.

**Horizontal total stress**

Shale, which is softer than the reservoir rock, accumulates less stress.

**Vertical total stress**

Despite the overburden remains constant, the vertical total stress changes to satisfy stress balance.
While caprock stability is maintained, preventing the risk of CO$_2$ leakage, fault stability within the reservoir decreases.
Fault instability is confined within the pressurized reservoir, so fault rupture will be arrested, limiting large events.
The plane where slip accumulates starts to develop the fault core, which is usually of low-permeability.
Every natural earthquake enhances the fault core and damages a larger extension of rock around it.
Induced microseismicity only causes local growth of the damage zone due to large stress inhomogeneity.
Natural and induced seismicity affect fault growth differently

- Geologic carbon storage remains a safe option

- Sedimentary formations are rarely critically stressed

- Overpressure causes inhomogeneous stress changes around the fault, leading to rupture arrest

- Large microseismicity may be induced if no pressure management is performed

- Large earthquakes (M>4) might nucleate at depths greater than 5 km, within the critically stressed crystalline basement

- A low-permeability sedimentary baserock limits pressurization of the critically stressed basement, reducing the likelihood of inducing felt seismicity
This project has received funding from the European Research Council (ERC) under the European Union’s Horizon 2020 research and innovation programme (grant agreement No 801809)