EGU2020-21428

EGU live chat, 07 May 2020, 14:00 – 15:45

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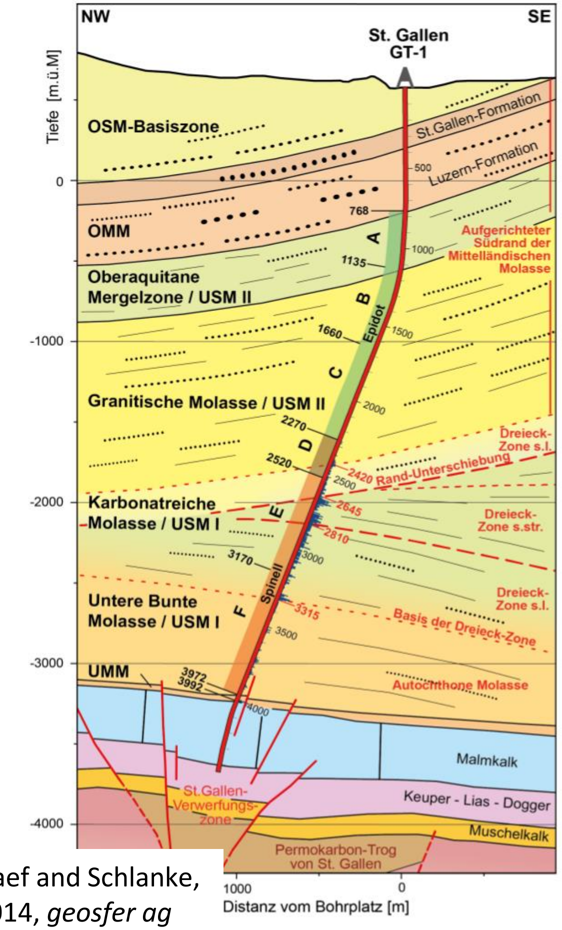
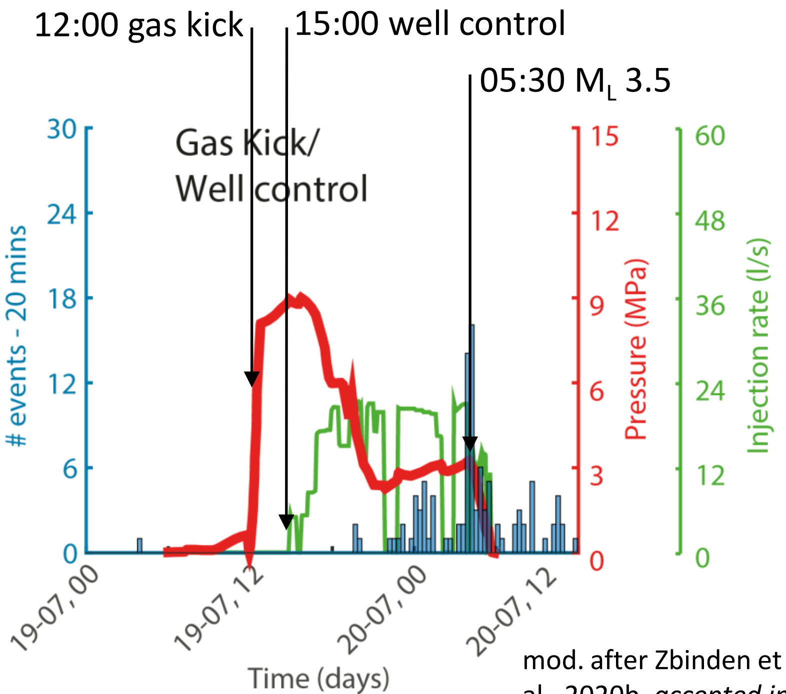
Multi-phase hydromechanical modeling of induced seismicity: general insights and the case study of the deep geothermal project in St. Gallen, Switzerland

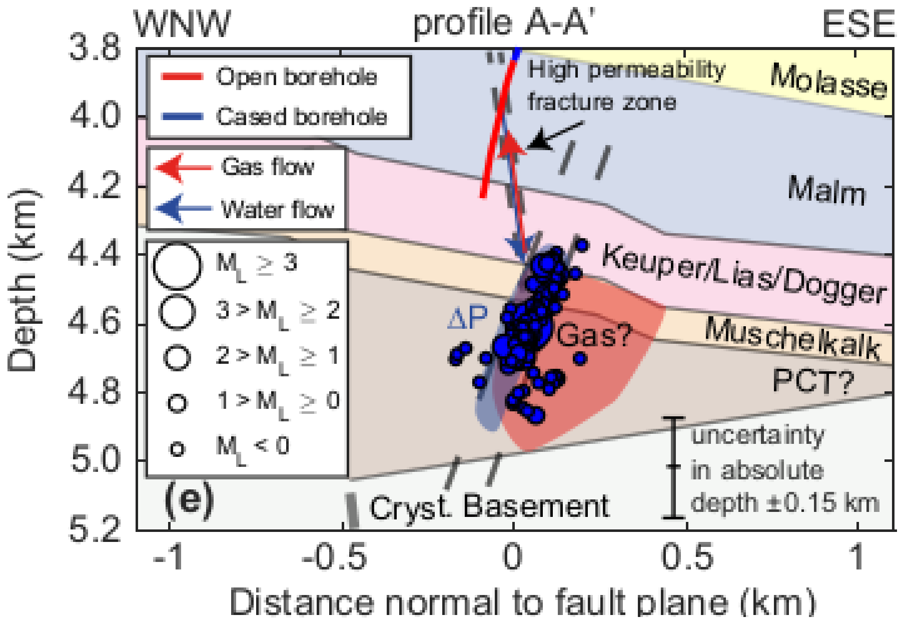


Naef and Schlanke, 2014, *geosfer ag*

The deep geothermal project in St. Gallen (2013) is a unique case study where an **induced seismic sequence occurred almost simultaneously with a gas kick**, suggesting that the gas may have affected the induced seismicity.



mod. after Zbinden et al., 2020b, *accepted in Solid Earth*

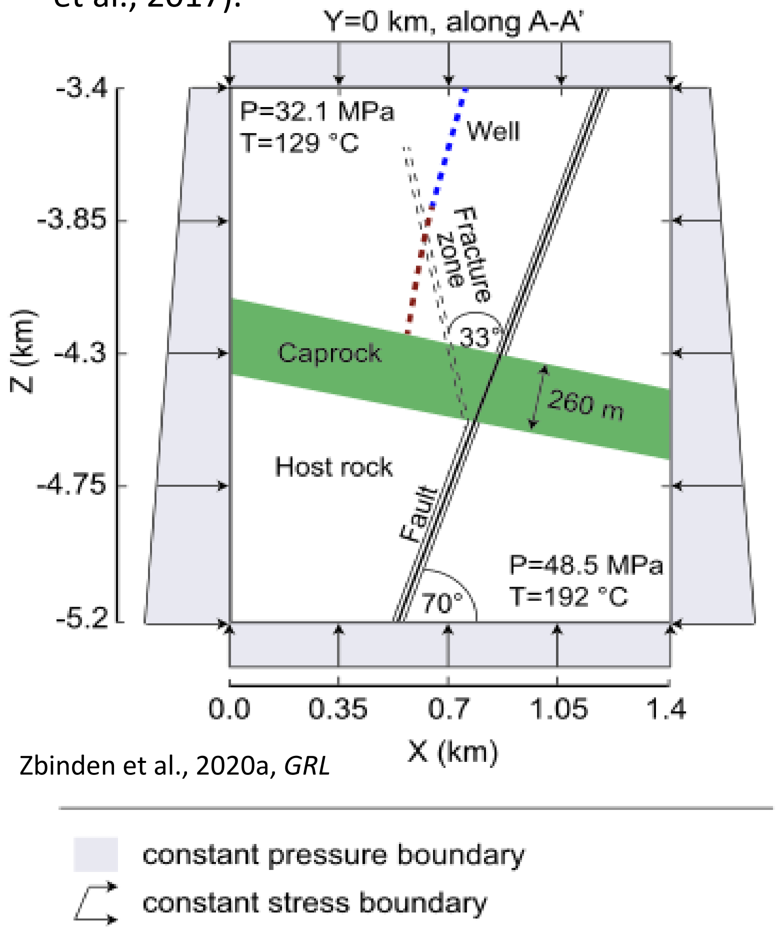


Zbinden et al., 2020b, *accepted in Solid Earth*

Conceptual model: Due to the pressurization, acidification and the shear slip associated with an injection test (14 July) and two acid stimulations (17 July), **a pathway opened up for the gas** to reach the well through a permeable fracture zone (Zbinden et al., 2020a, *GRL*) and to cause the gas kick (19 July). The fluid injected during the **well control measures (20 July) and the gas destabilized a larger patch on the fault**, leading to the seismic sequence that included the ML 3.5 main shock.

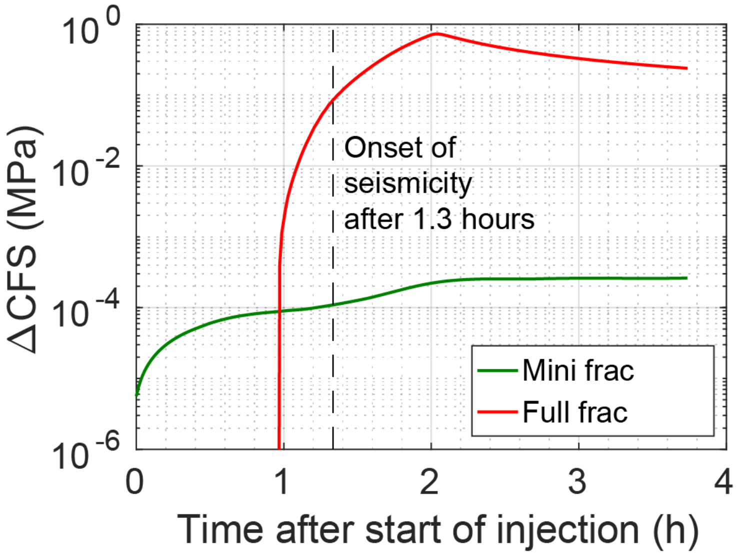
Hydro-mechanical modeling with TOUGH-FLAC: Poroelasticity or hydraulic connection?

The **injection test (14 July)** is simulated with TOUGH-FLAC (Rutqvist, 2011; Blanco-Martín et al., 2017).

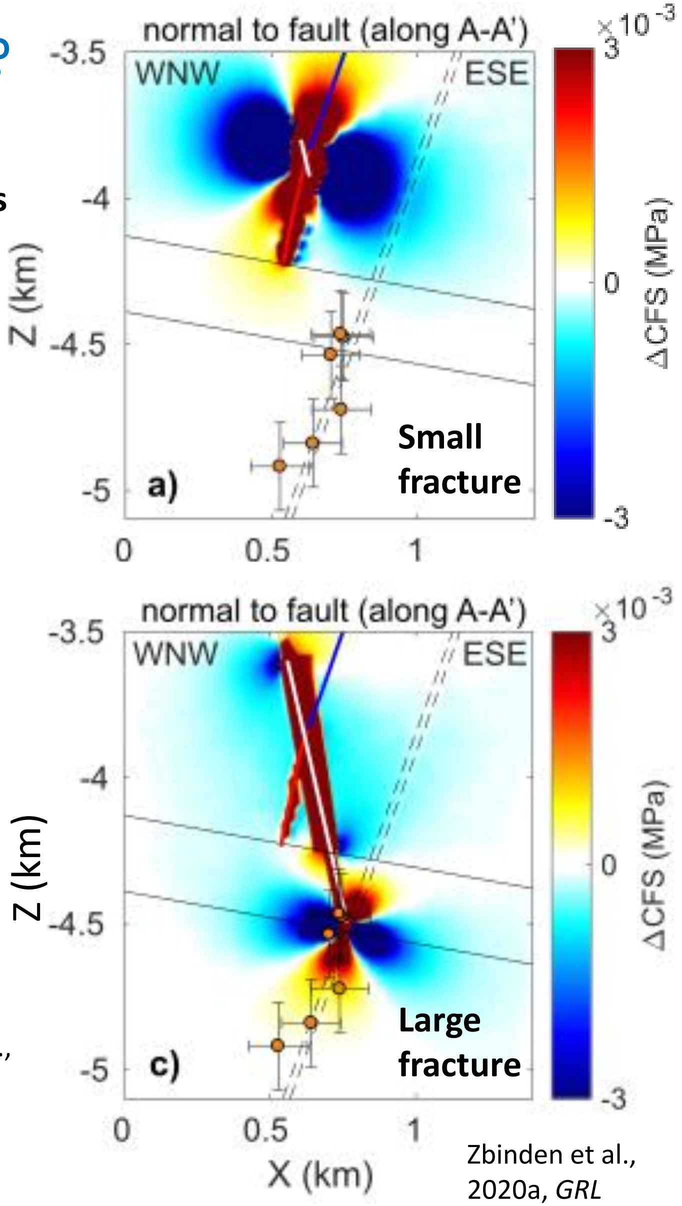


Zbinden et al., 2020a, *GRL*

For a scenario without a hydraulic connection between the well and the reactivated fault (**small fracture** – top right figure), **Coulomb stress changes at the locations of the induced events are very low (<10^{-3} MPa).** In the case of a hydraulic connection (**large fracture** – bottom right), **stress changes are about three orders of magnitude larger (almost 1 MPa).** Moreover, stress starts to change already after one hour, i.e. before the onset of seismicity (bottom). Thus, **we consider it more plausible that the direct pressure effect through a permeable hydraulic connection rather than poroelasticity** is the predominant mechanism in the St. Gallen reservoir (Zbinden et al., 2020a).



mod. after Zbinden et al., 2020a, *GRL*



Zbinden et al., 2020a, *GRL*

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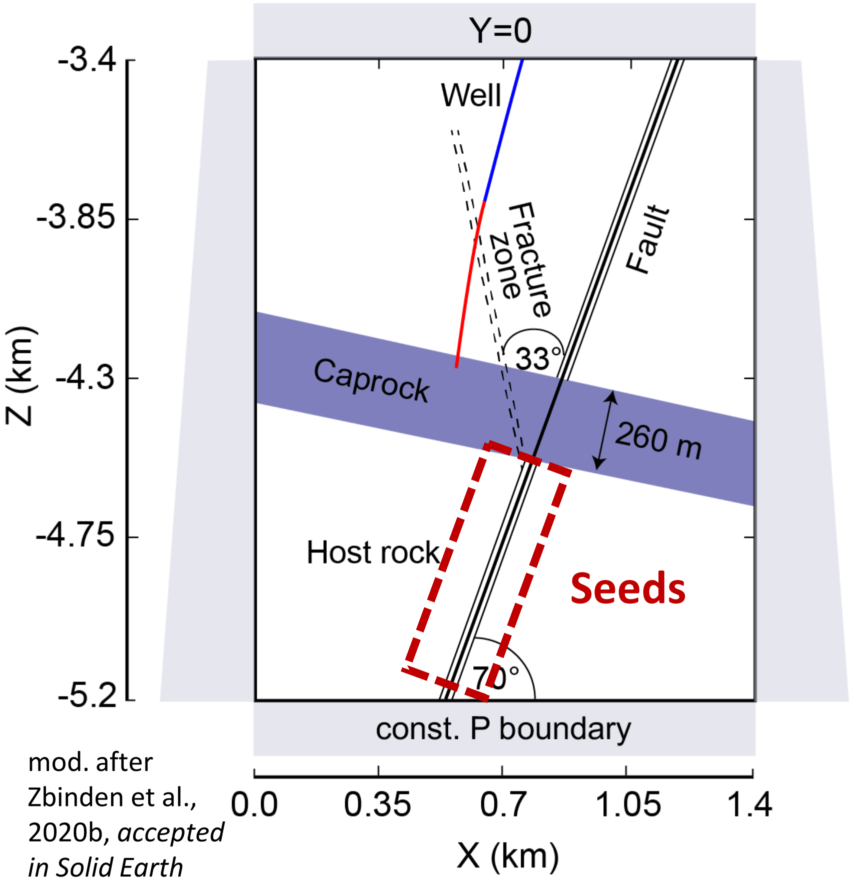
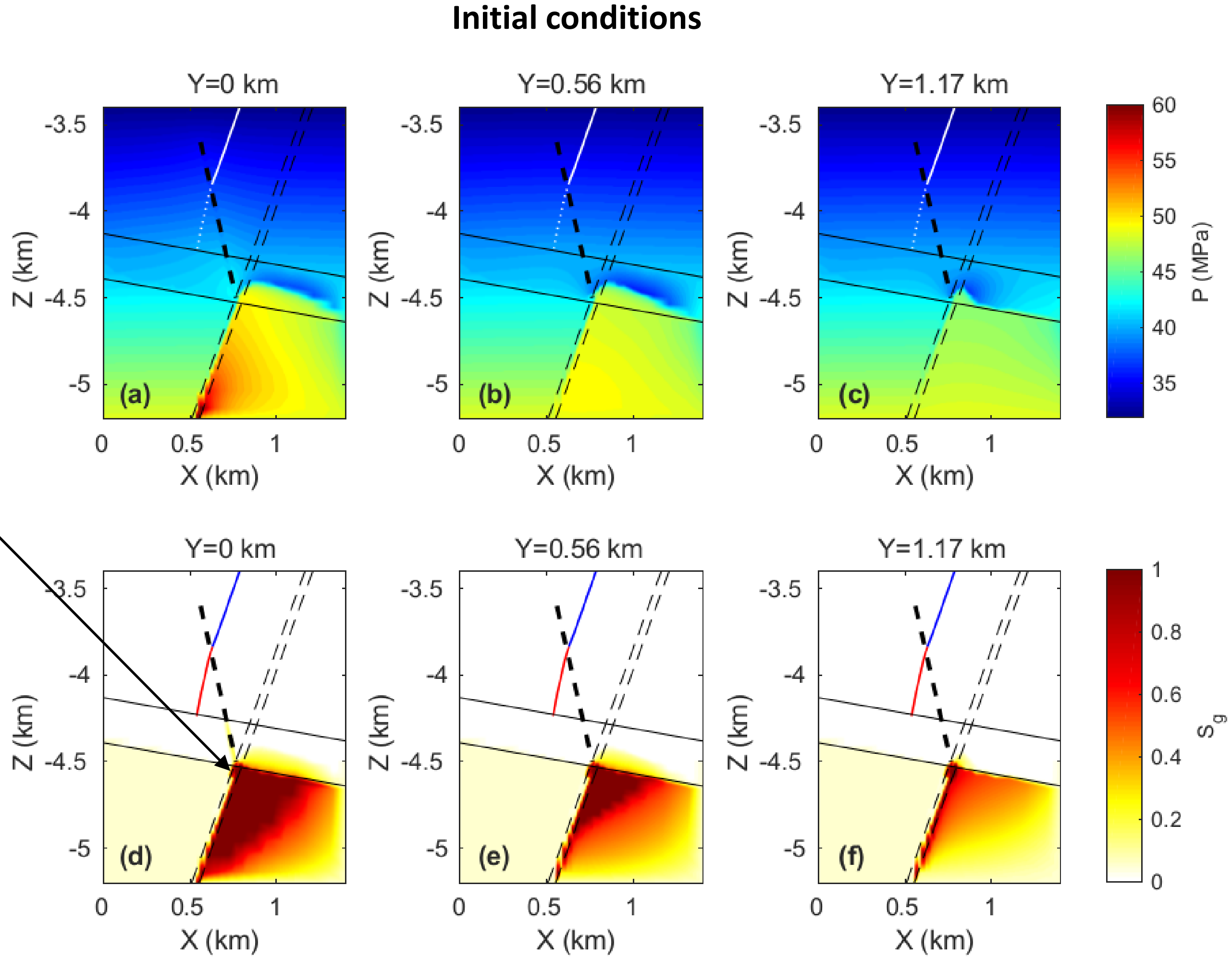
Multi-phase modeling with stochastic TOUGH2-seed simulator: did the gas contribute to enhance the seismicity?

2D view of 3D model: Randomly distributed **failure points (seeds)** are positioned on the lower part of the fault (for more details on TOUGH2-seed, see Rinaldi and Nespoli (2017) and Zbinden et al. (2020b)).



mod. after Zbinden et al., 2020b, *accepted in Solid Earth*

Overpressurized gas (with respect to undisturbed conditions) is initially sealed by the fault. **The fault seal breaches** at Z=-4.5 km at simulation time t=0 to initiate the gas kick. Additional permeability changes further down on the fault (Z≈-4.6 km) are assumed due to the two largest events in the sequence (including the ML 3.5 event).



Zbinden et al., 2020b, *accepted in Solid Earth*

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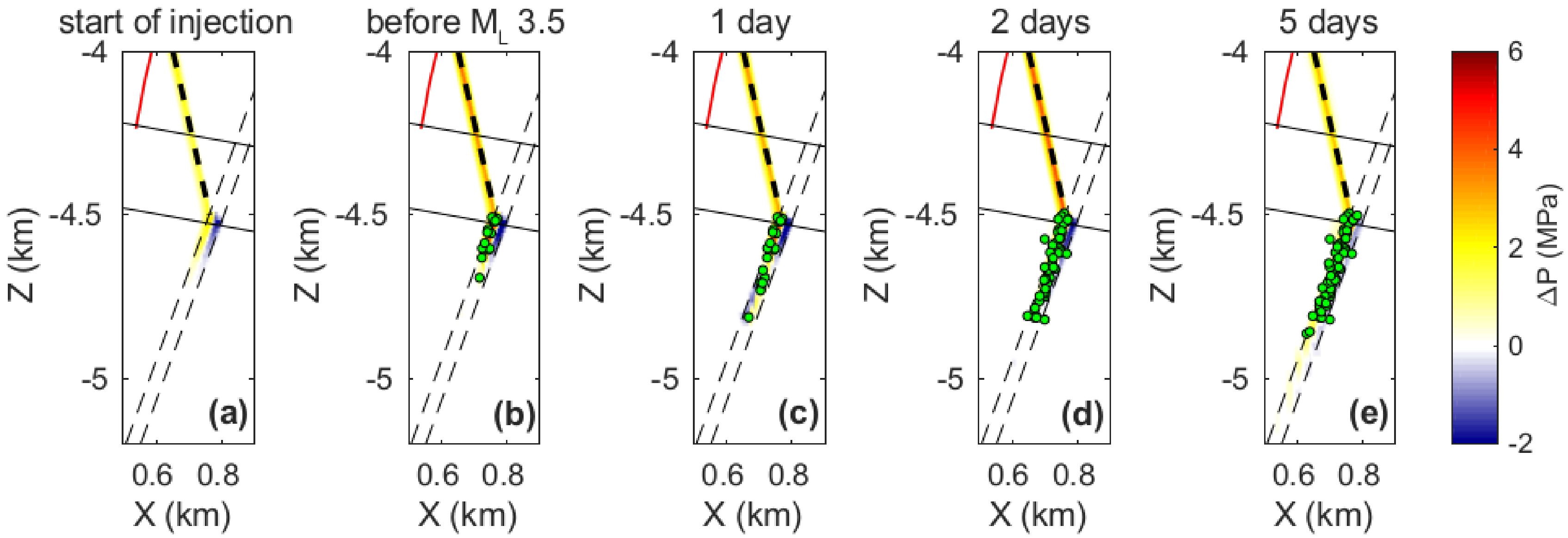
Simulated seismicity during the gas kick and well control injection

The multi-phase fluid flow causes pressure changes on the fault, which induces the seismicity (bottom figure). Since we do not account for poroelastic effects in TOUGH2-seed, the seismicity occurs only in regions with positive pressure changes. The simulated cumulative number of events (1000 model realizations) agrees with the observed seismicity with magnitudes above the magnitude of completeness *Mc* (top right). The stochastic model allows to quantify the potential effect of the gas: **about 40 % of the seeds are directly triggered by the in-place gas** (bottom right). More details can be found in Zbinden et al. (2020b).



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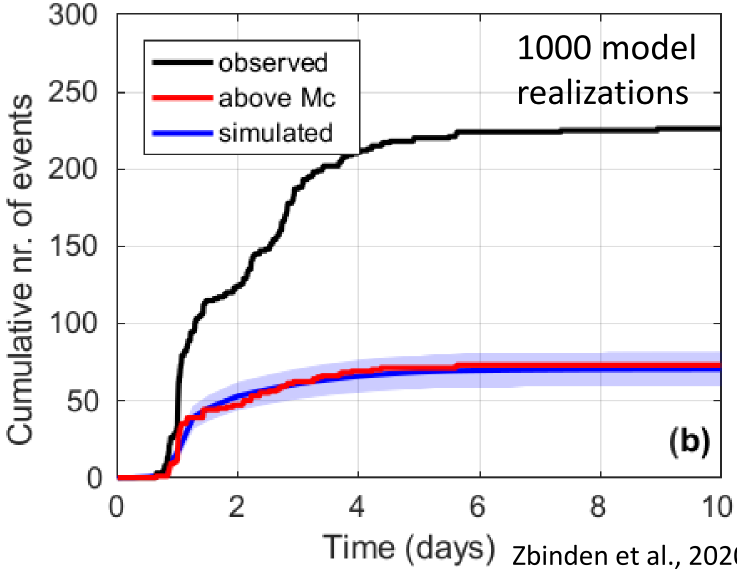

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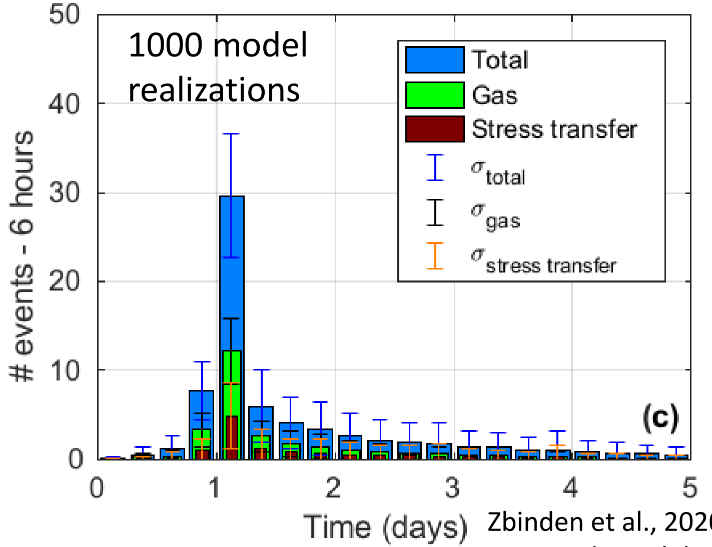

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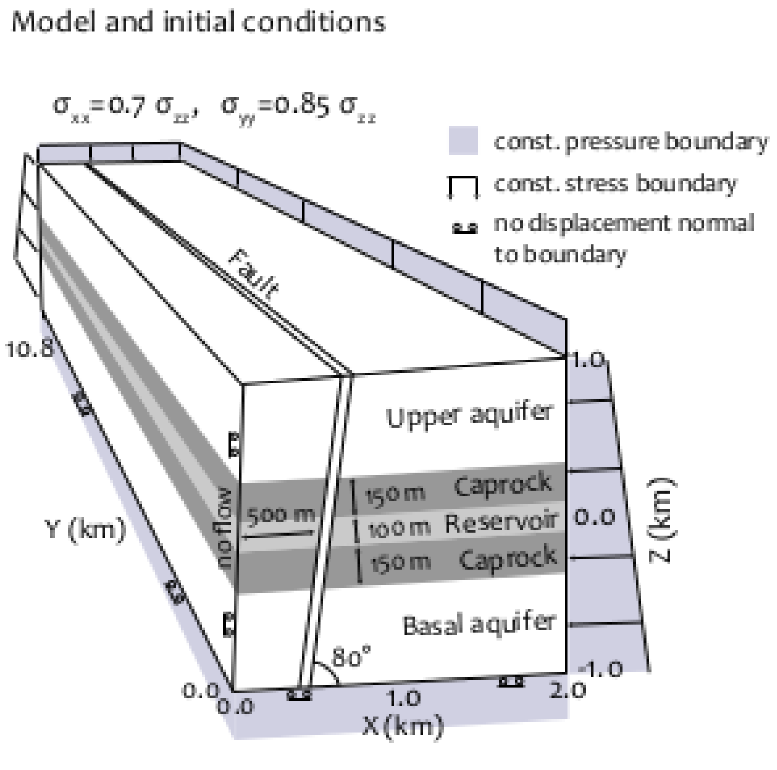
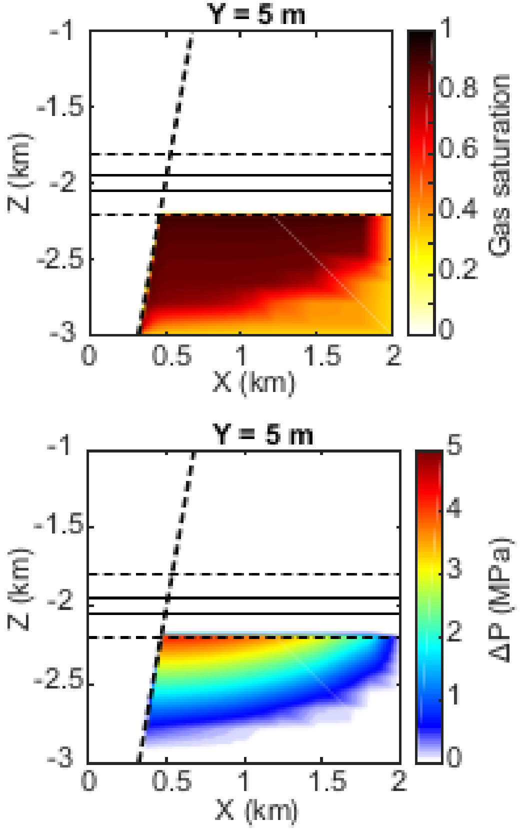
Insights from general multi-phase flow simulations

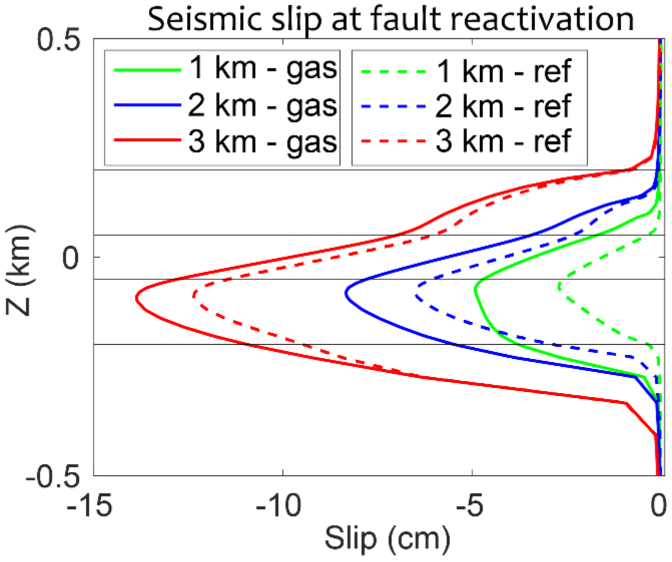
3D hydro-mechanical model (TOUGH-FLAC – Rutqvist, 2011): A **gas reservoir pressurizes the lower right part of the fault** by ~4 MPa. The fault core and lower caprock are sealing and prevent the gas from reaching the injection reservoir. Due to the high capillary entry pressure, the fault core is not directly pressurized by the gas, but it is indirectly stressed by poroelastic effects. Water is injected into the laterally confined reservoir.



Zbinden et al., 2018, *TOUGH symposium*



Overpressurized gas can enhance fault slip if the gas is located on the foot wall. The **influence of gas decreases with reservoir depth**, since tectonic stresses become larger.



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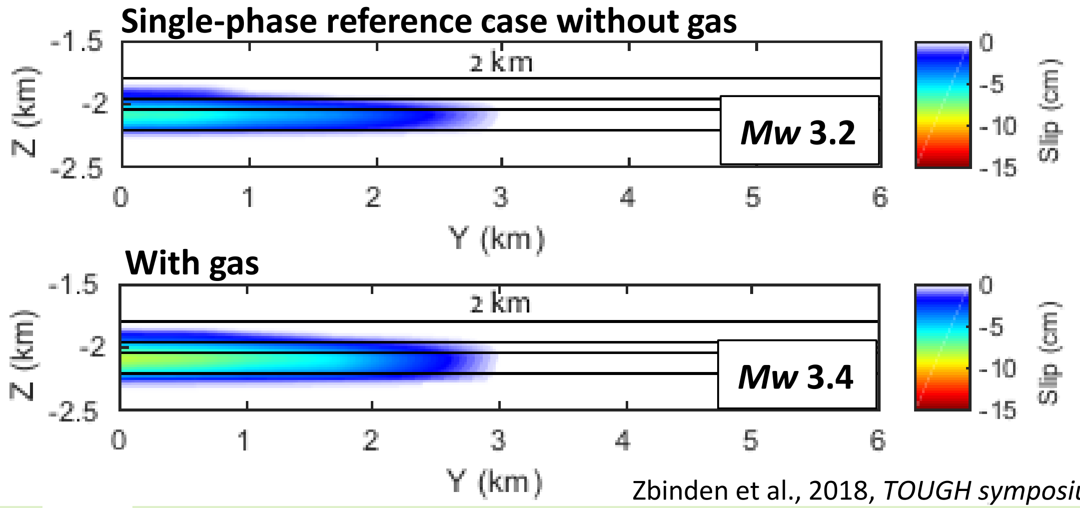

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Four take home messages

- The direct pressure effect rather than poroelasticity is the predominant mechanism at St. Gallen.
- The spatio-temporal evolution of the induced seismicity can be reproduced with a multi-phase fluid/stochastic geomechanical model.
- The gas could have contributed to enhance the induced seismicity in the St. Gallen reservoir.
- More generally: The presence of an overpressurized gas plume can increase the event magnitude, but the influence of the gas decreases with increasing depths.

2013, Stadt St.Gallen / St.Galler Stadtwerke

Papers

Zbinden, D., Rinaldi, A. P., Diehl, T., & Wiemer, S. (2020a). Hydromechanical modeling of fault reactivation in the St. Gallen deep geothermal project (Switzerland): Poroelasticity or hydraulic connection? *Geophysical Research Letters*, 47, e2019GL085201. https://doi.org/10.1029/2019GL085201

Zbinden, D., Rinaldi, A. P., Diehl, T., & Wiemer, S. (2020b): Potential influence of overpressurized gas on the induced seismicity in the St. Gallen deep geothermal project (Switzerland). *Accepted in Solid Earth.* https://doi.org/10.5194/se-2019-156

Zbinden, D., Rinaldi, A. P., & Wiemer, S. (2018). Modeling the effect of a gas phase during injection-induced fault reactivation. *Proceedings of the TOUGH Symposium 2018*, Lawrence Berkeley National Laboratory, Berkeley, CA, USA. https://www.research-collection.ethz.ch/handle/20.500.11850/390174

This work was supported by a Swiss National Science Foundation (SNSF) Ambizione Energy grant (PZENP2_160555).