The 2019-2022 sequence of induced seismicity below the city of Strasbourg, France : insights from large-scale THM reservoir modeling

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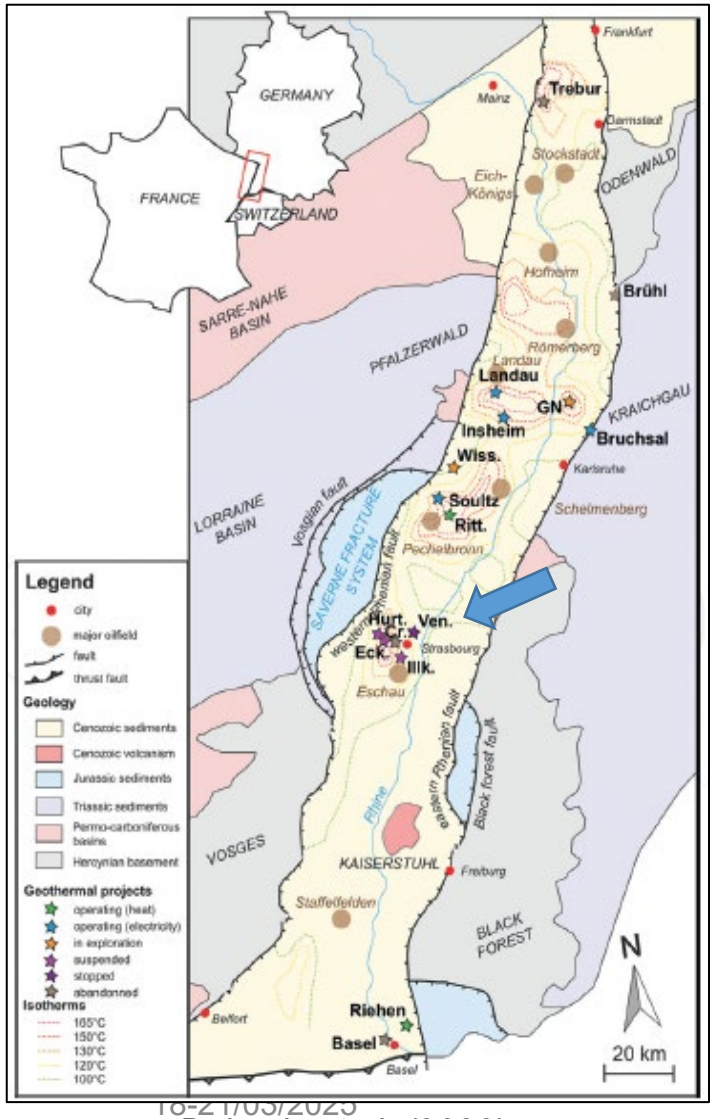
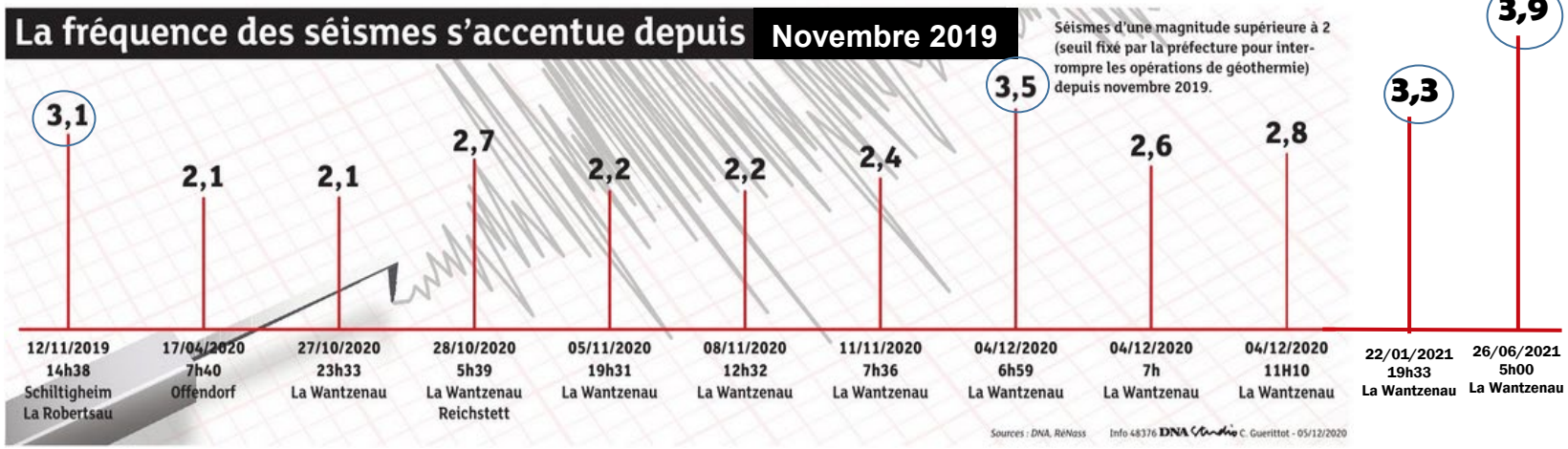
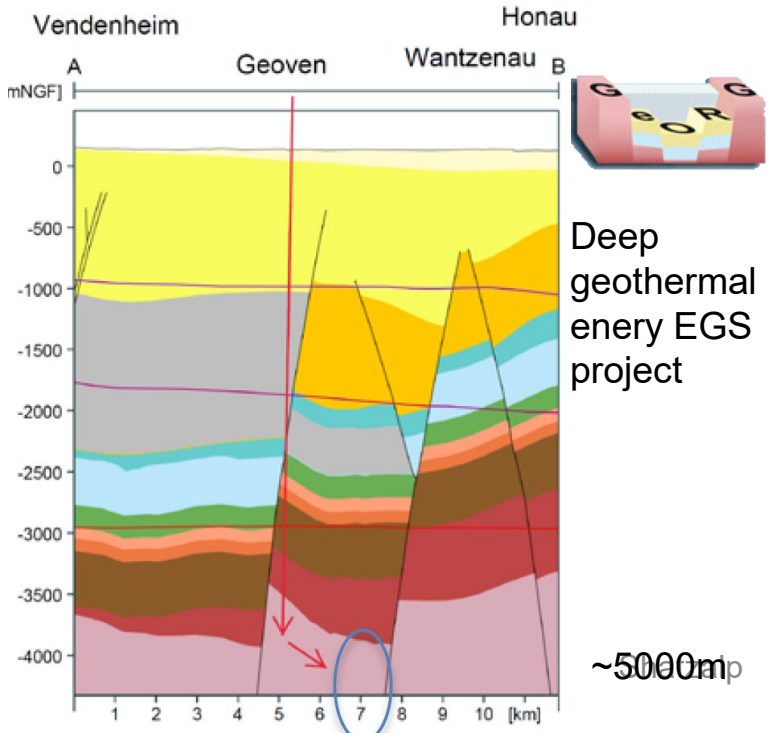


Dalmais et al. (2022)



Seismic sequence with 12 Ml>2 events (4 Ml>3) close to the city of Strasbourg (France)



Deep geothermal enery EGS project

~5000m

Georhin site (Vendenheim)

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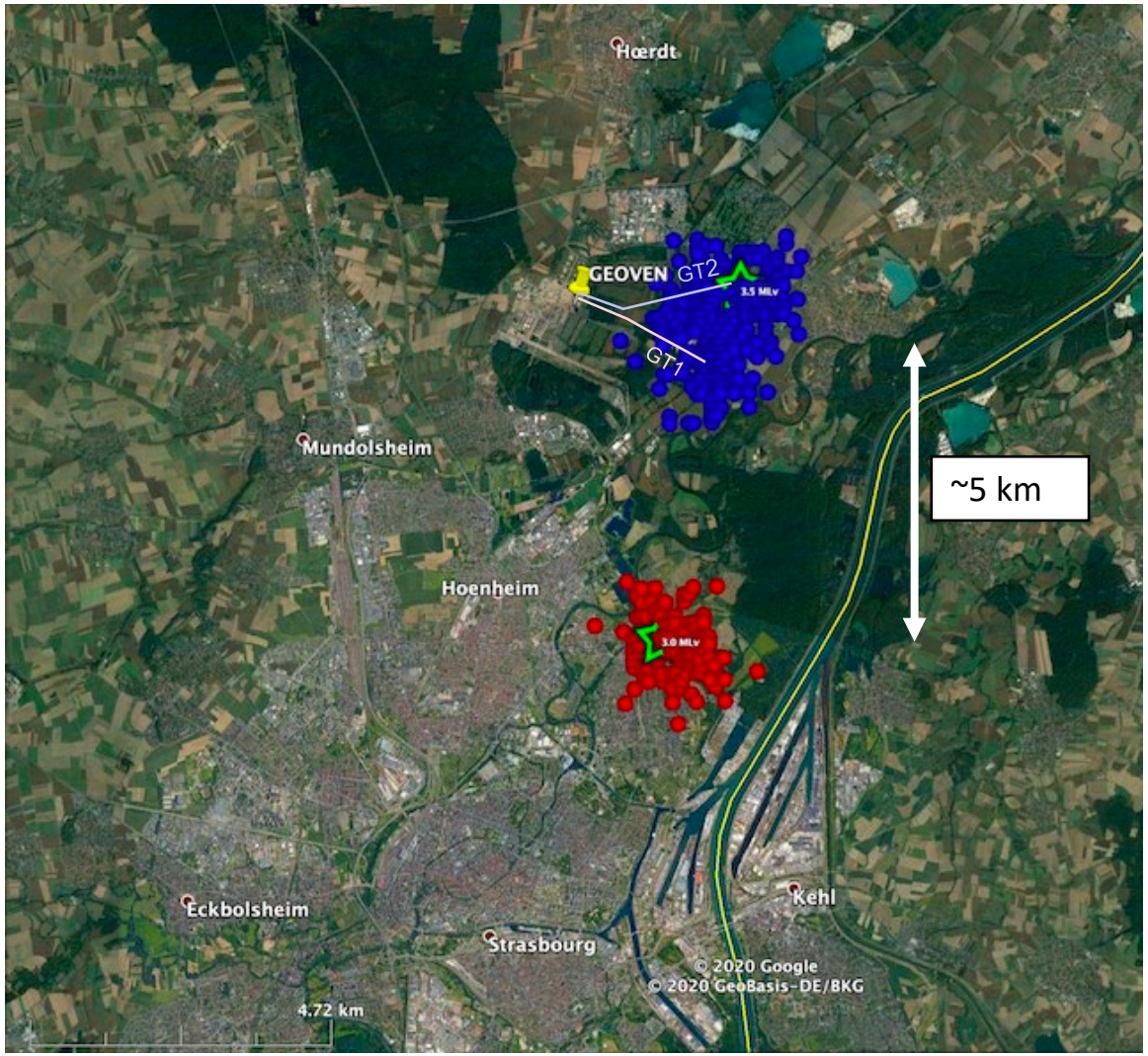
Two seismic swarms



Northern swarm
Wells GT1 and GT2 – Vendenheim/Wantzenau

Activity : March 2018 – Nov. 2022

Catalog BCSF-RéNaSS :

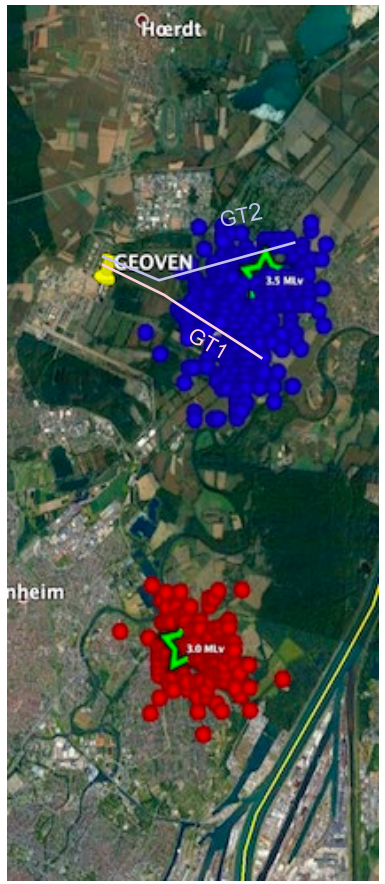
- **3** eq M >3 (Mlv 3.9 on 26/6/2021; Mlv 3.6 on 4/12/2020; Mlv 3.3 on 22/1/2021)
- **11** eq 2<M<3
- **23** eq 1.5<M<2
- **309** eq M<1.5

Southern swarm
Strasbourg/Roberstau

Activity : Nov. 2019 – Apr. 2020

Catalog BCSF-RéNaSS :

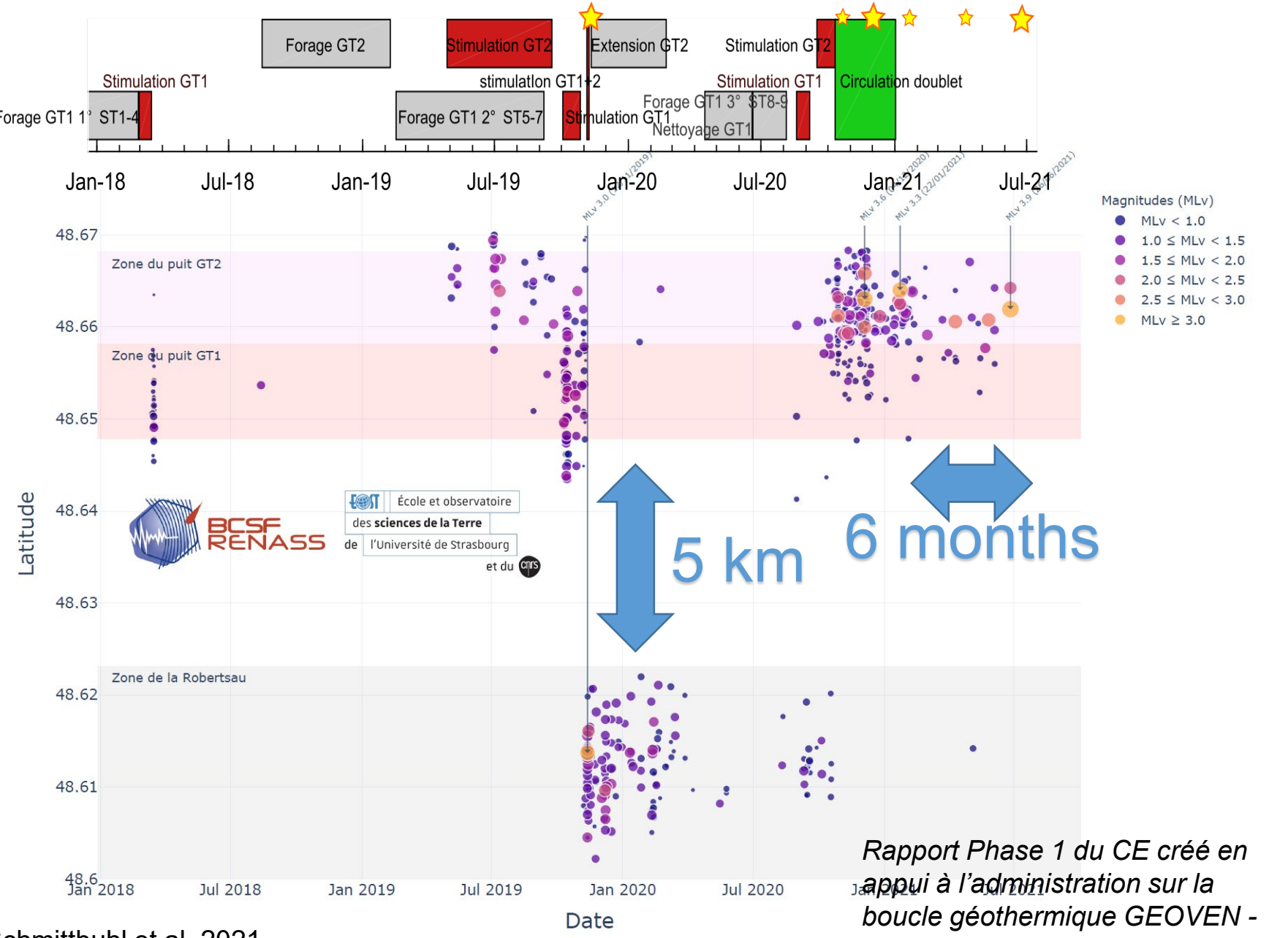
- **1** eq M >3 (Ml 3.0 on 12/11/2019)
- **3** eq 2<M<3
- **17** eq 1.5<M<2
- 105 eq M<1.5



Northern cluster

Southern cluster

Seismicity From 2018 (BCSF-RENASS)



Schmittbuhl et al, 2021

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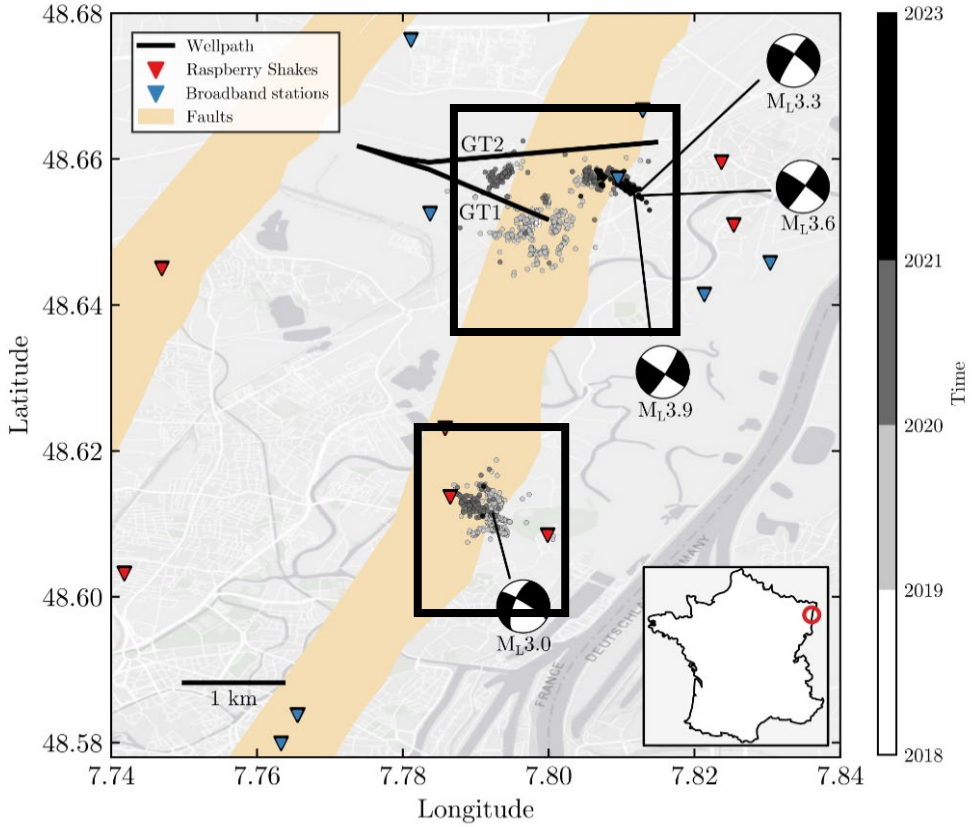
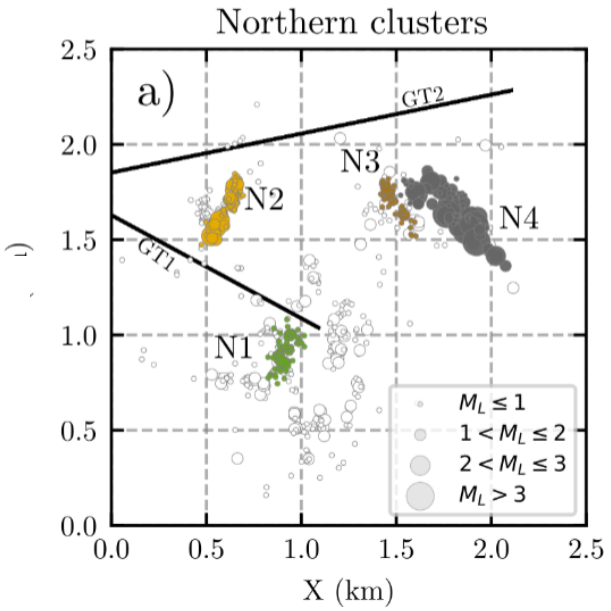
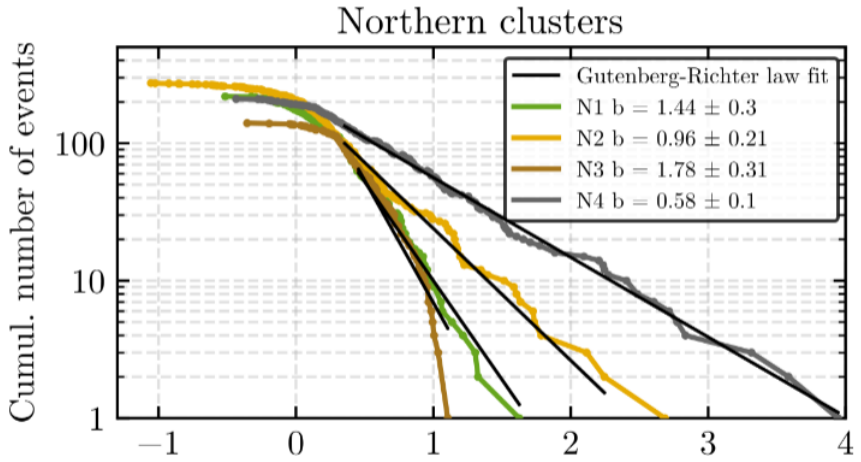
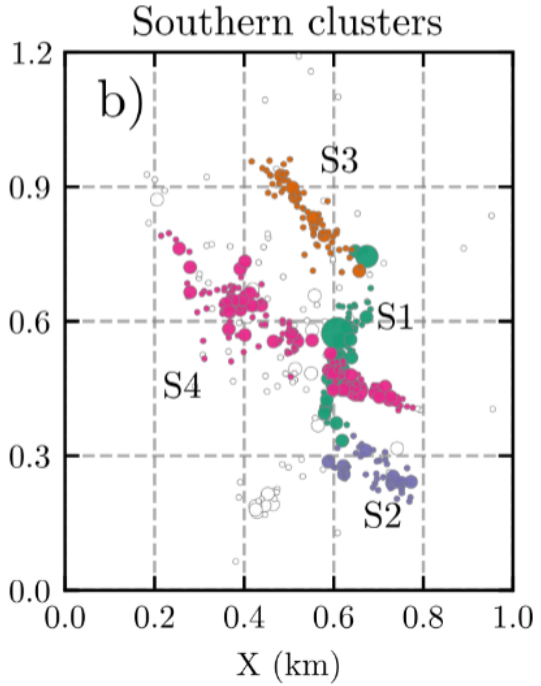
Clustering and b-values

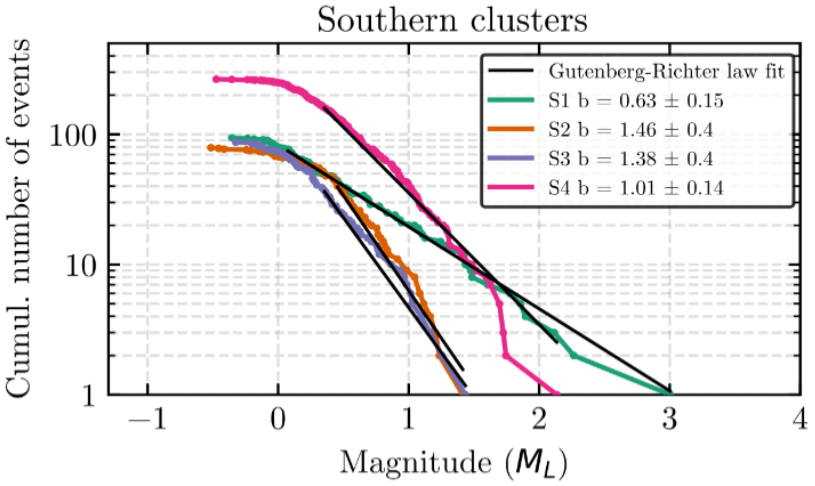


Minetto et al, 2025

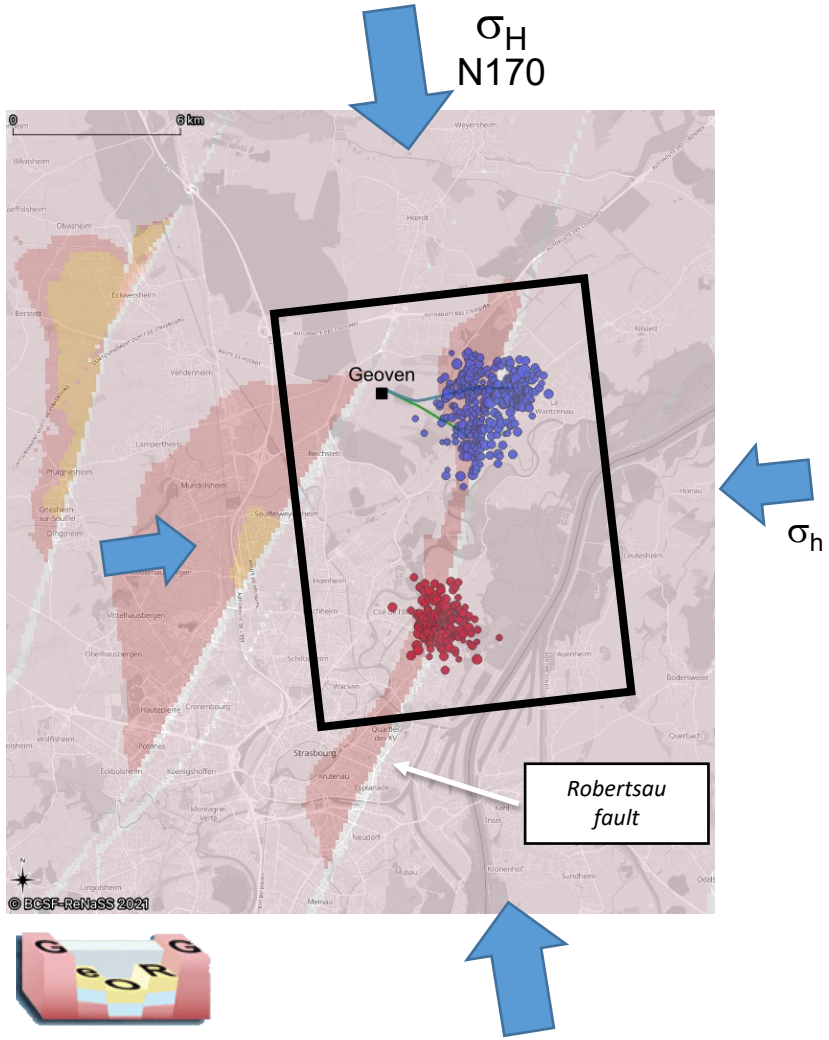


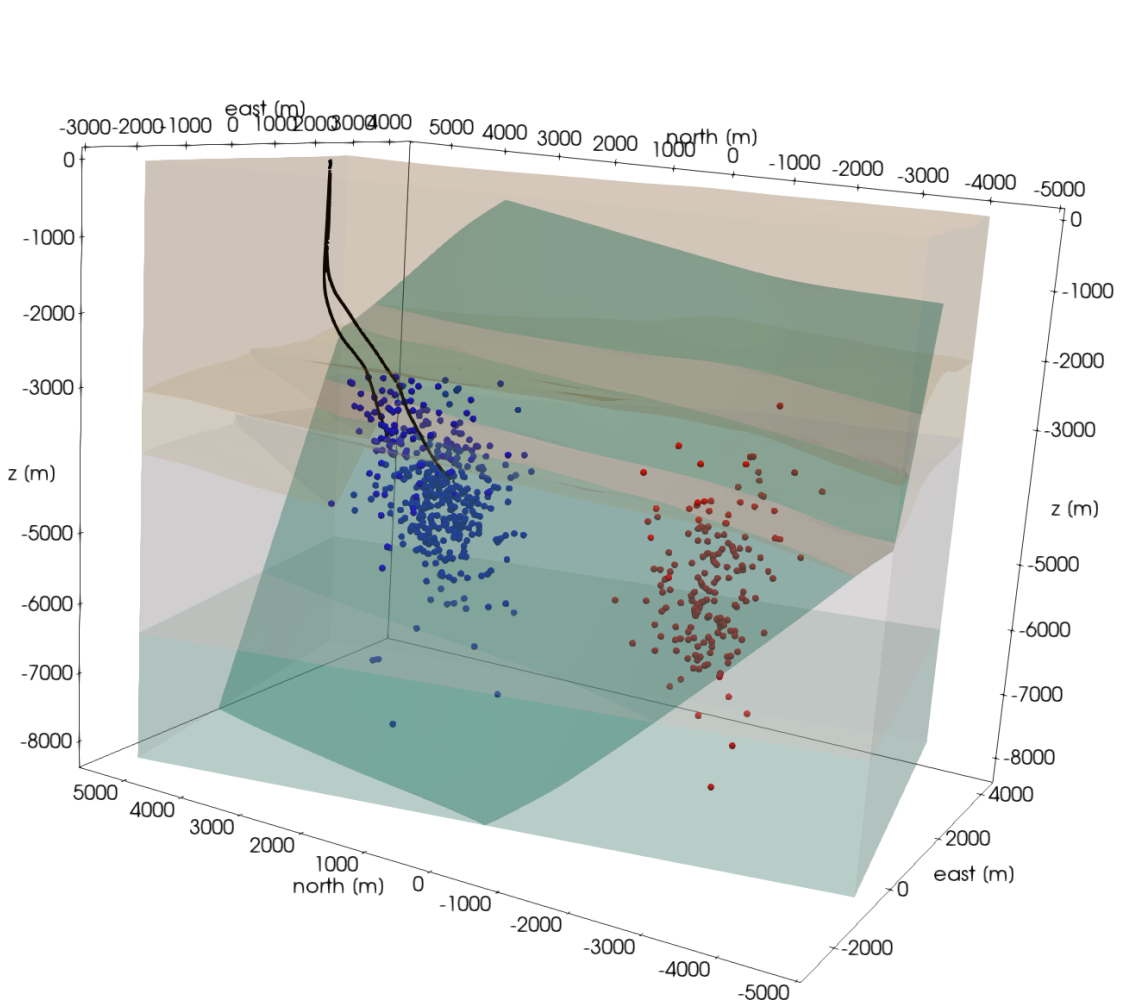






Geological context

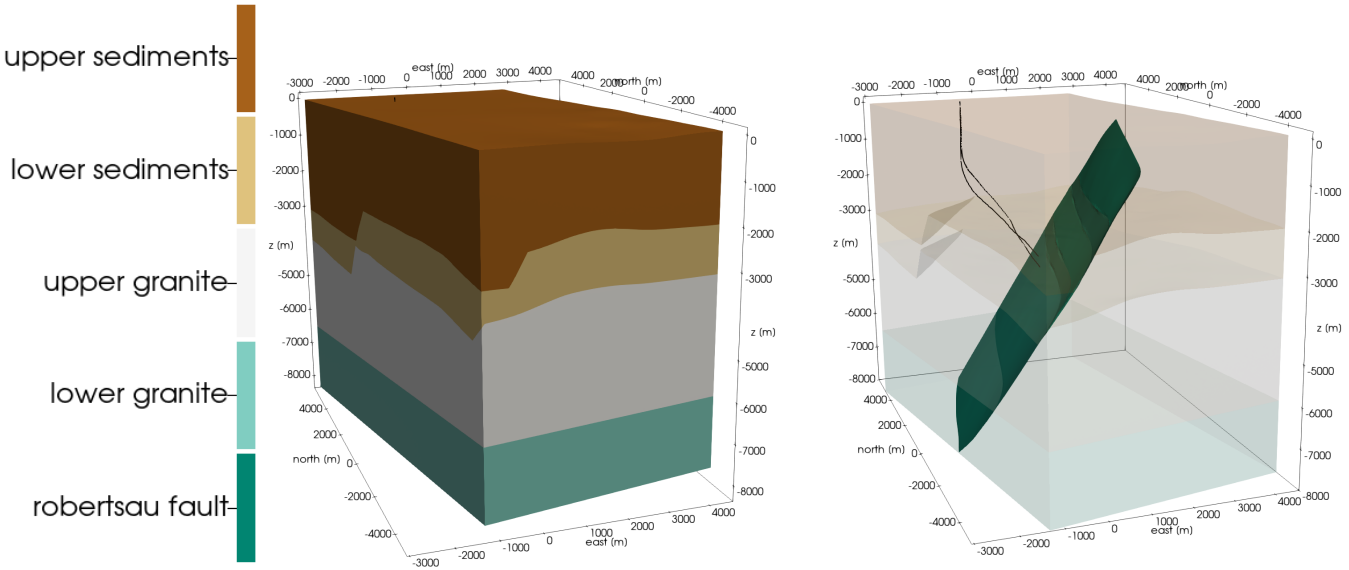




THM modelling

MOOSE Jacquey, A.B. & Cacace, M. (2017)

GOLEM



3D THM modeling

$$\frac{n}{K_f}\frac{\partial p_f}{\partial t} + \nabla \cdot \boldsymbol{q}_D = 0,$$

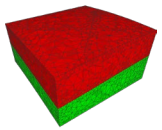
$$\boldsymbol{q}_D = -\frac{\boldsymbol{k}}{\mu_f} \cdot (\nabla p_f - \rho_f \boldsymbol{g}),$$

$$(\rho_b c_b)\frac{\partial T}{\partial t} + \nabla \cdot \boldsymbol{q}_T = 0,$$

$$\boldsymbol{q}_T = \rho_f c_f \boldsymbol{q}_D T - \lambda_b \nabla T,$$

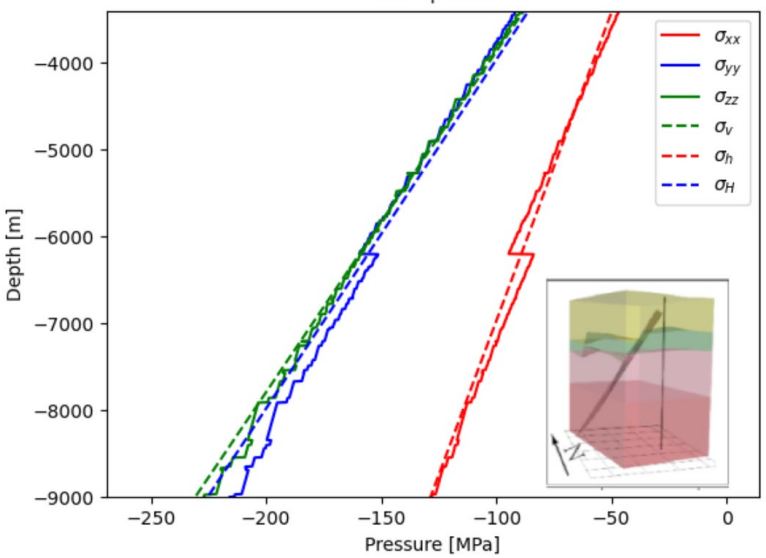
$$\nabla \cdot (\boldsymbol{\sigma}' - \alpha p_f \boldsymbol{I}) + \rho_b \boldsymbol{g} = 0,$$

$$\boldsymbol{\sigma}' = \mathcal{C} : (\epsilon - \frac{\beta_b}{3} T \boldsymbol{I}),$$



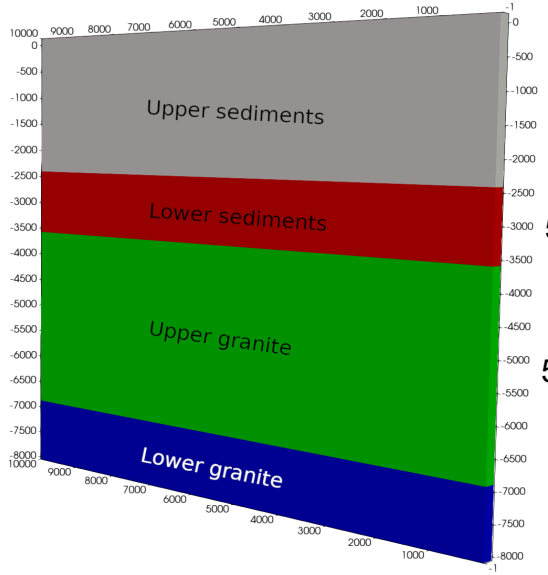
MeshIt [Cacace & Blöcher, 2015]

Surrugate model – parameter inversion



Observed stresses

'Mesured' stresses



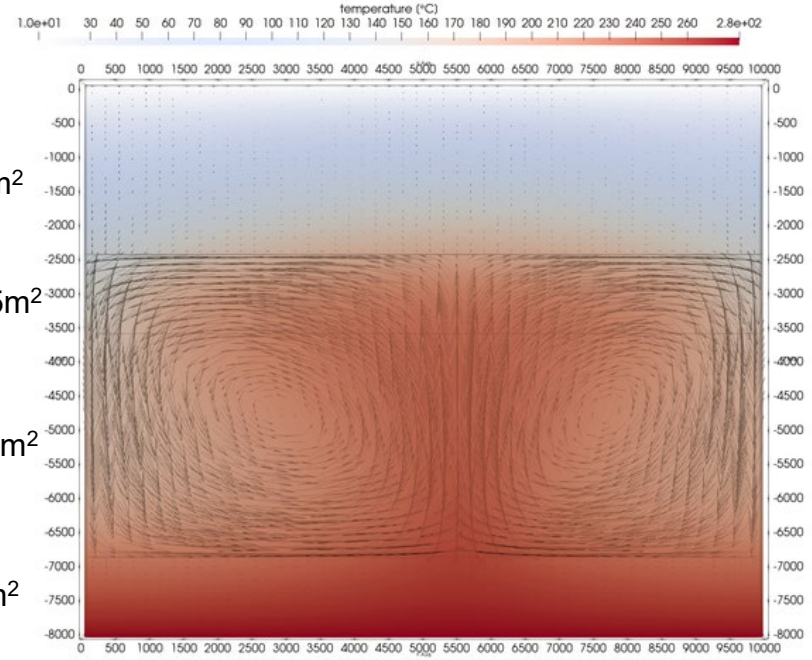
k

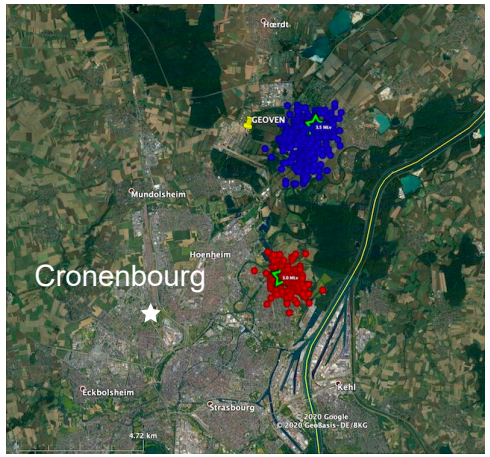
2e-16m²

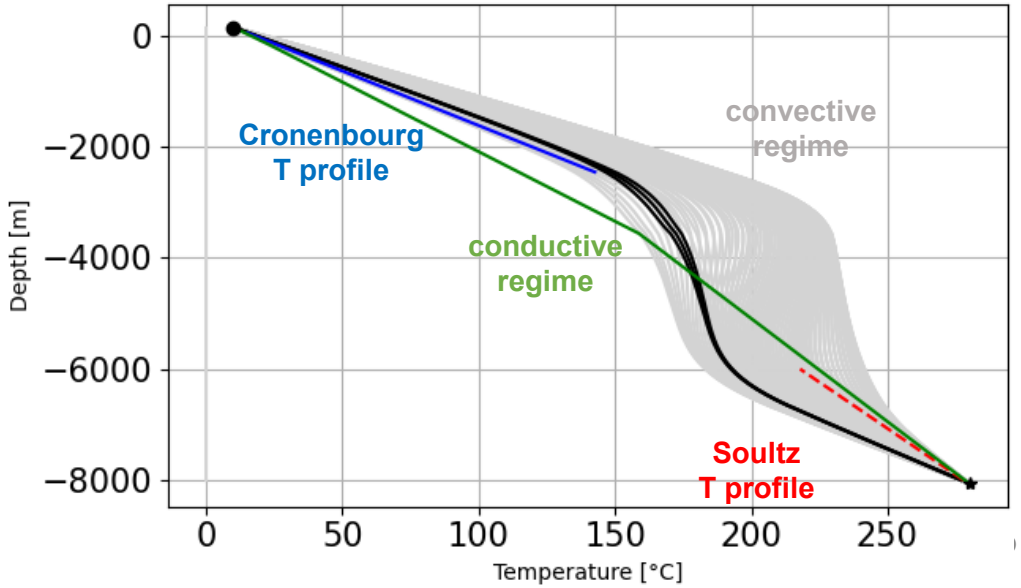
5.5e-15m²

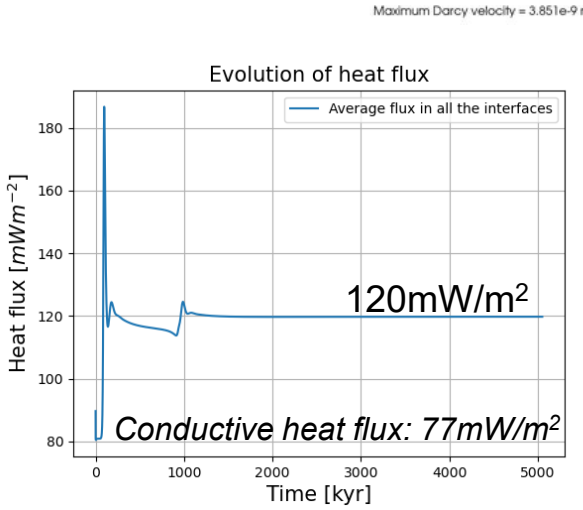
5.5e-15m²

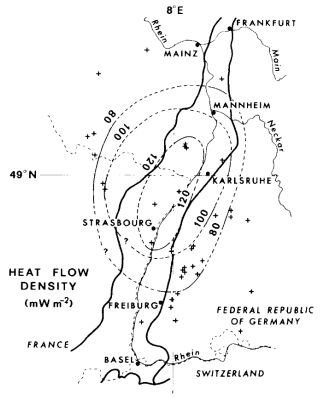
2e-16m²





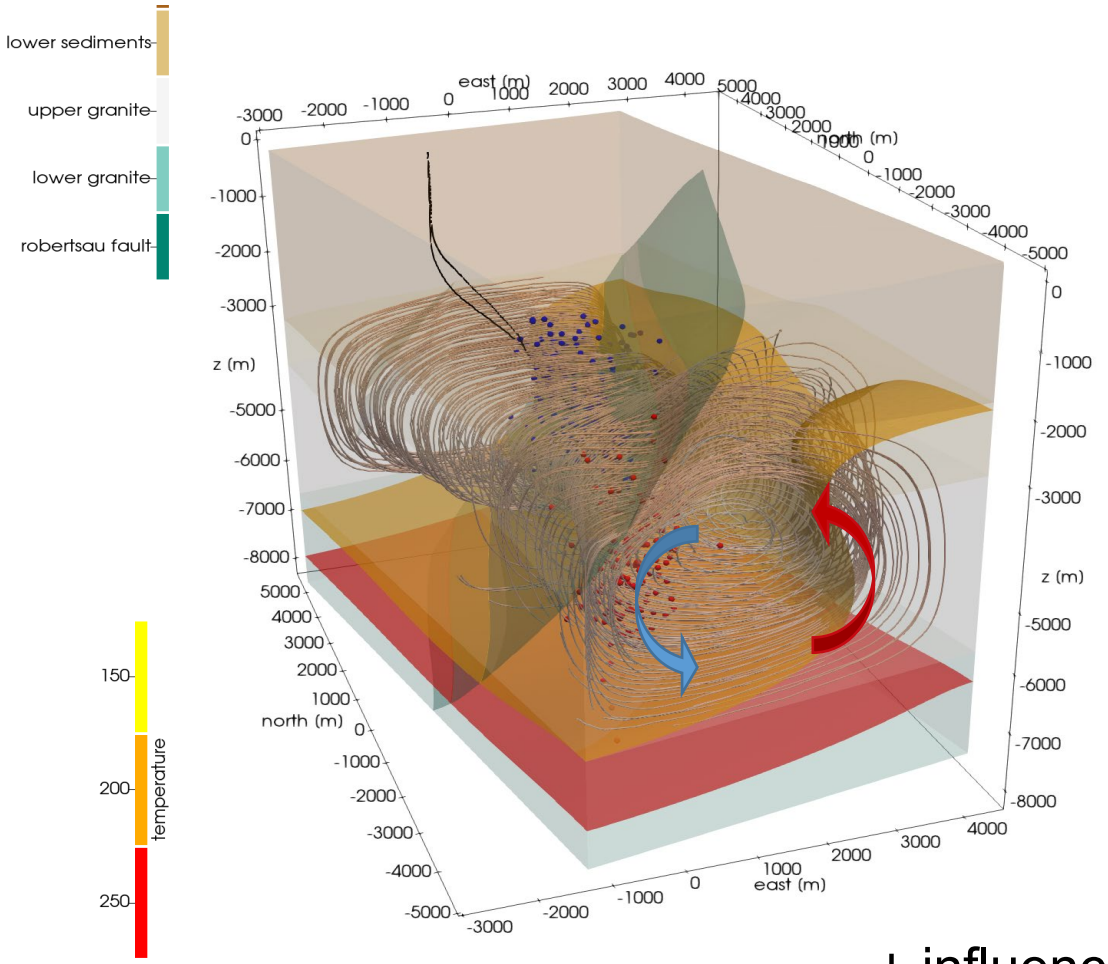


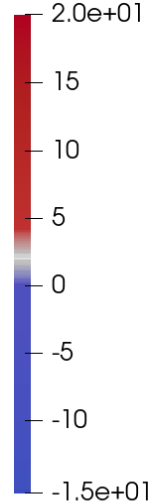


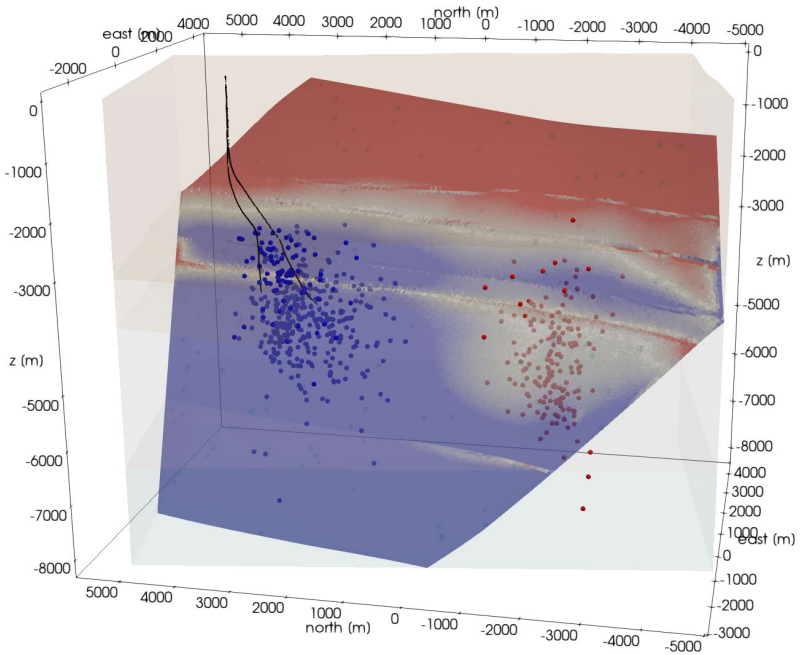


Clauser&Villinger, 1990

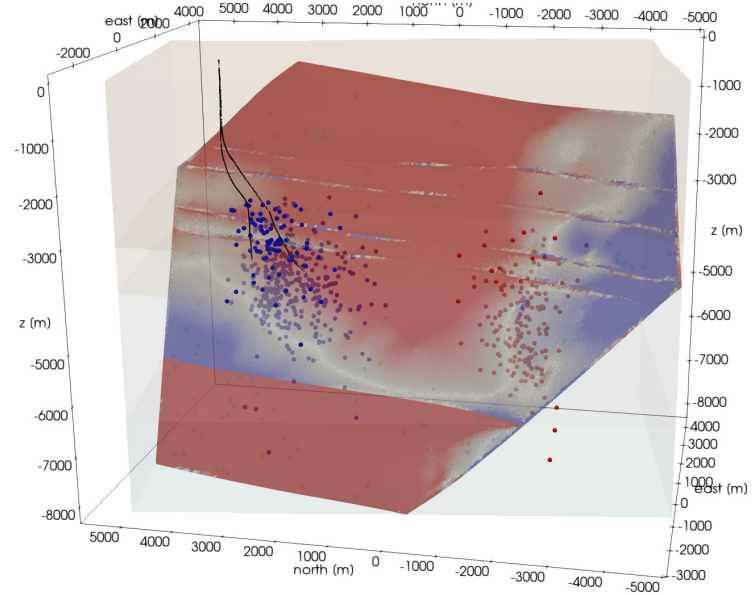
Full model – Hydro-thermal circulation and Coulomb Stresses







k
2e-16m²
5.5e-15m²

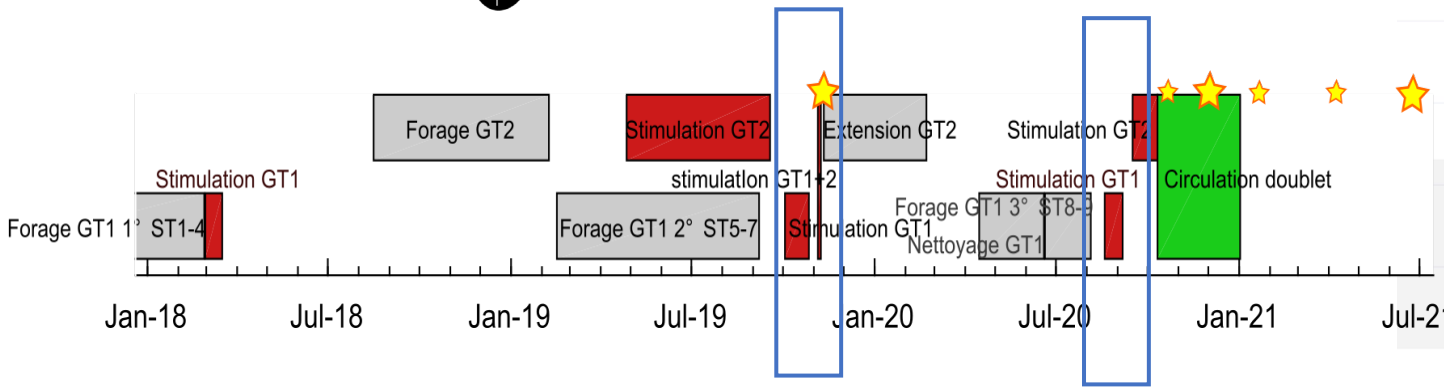


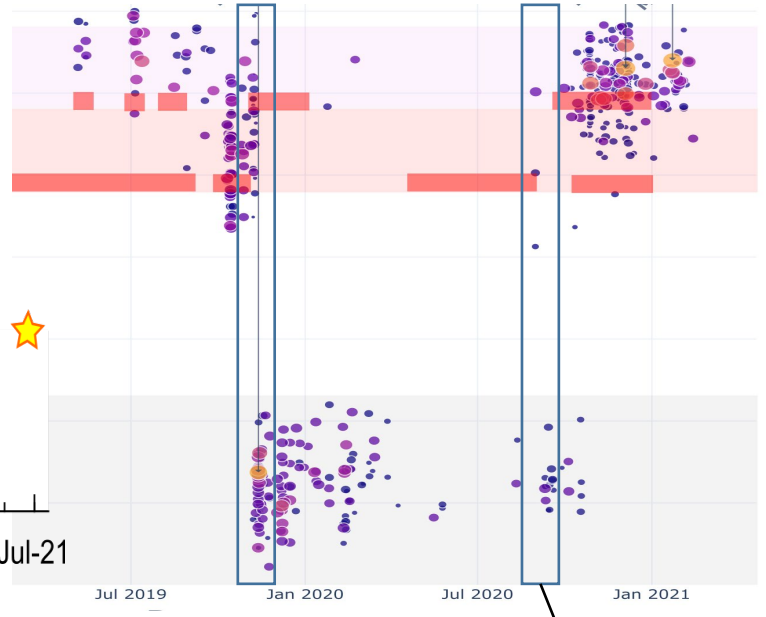
5.5e-15m²
2e-16m²

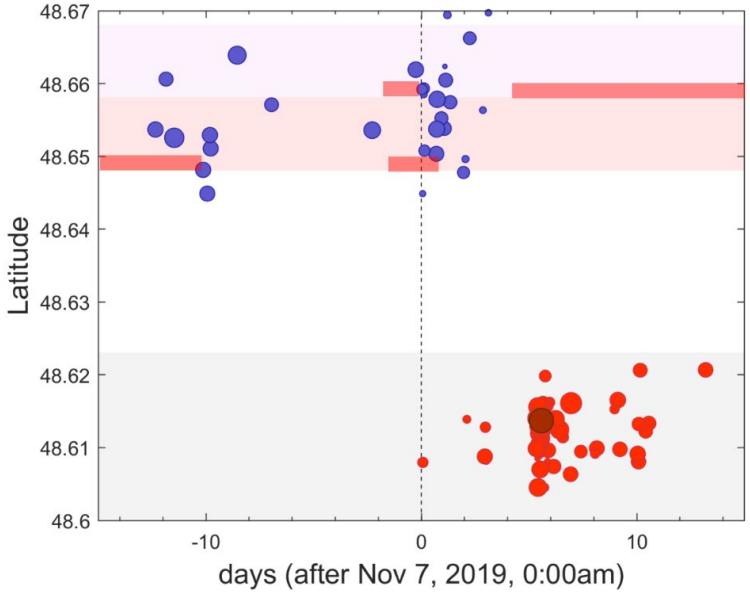
k
1e-18m²
1e-18m²
1e-18m²
1e-18m²

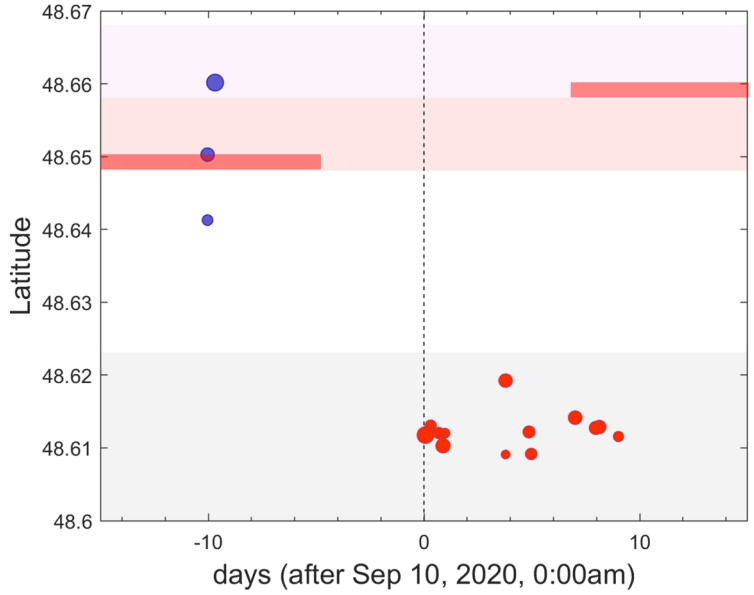
+ influence of fault kink

Fluid injections - observations









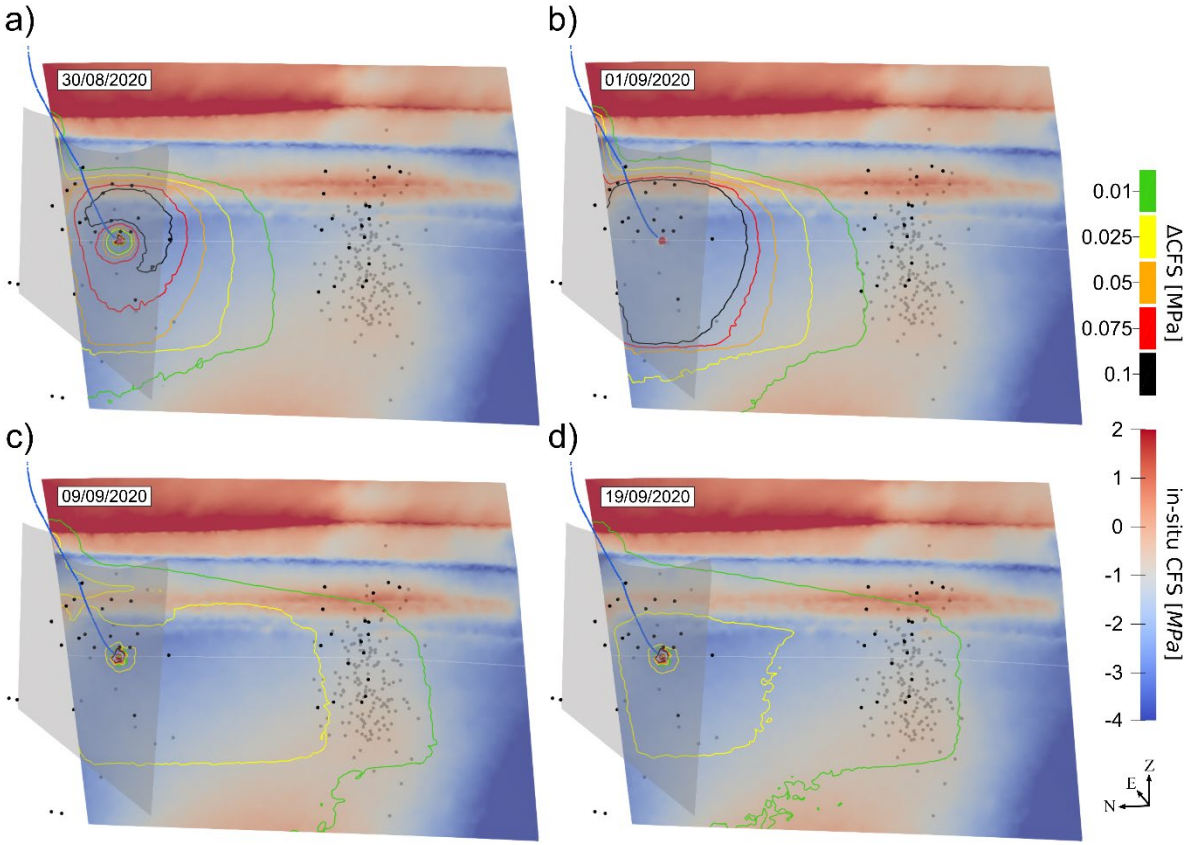
~10 day delay between GT1 well and the southern cluster

$$l \approx 4600 \text{ m}$$

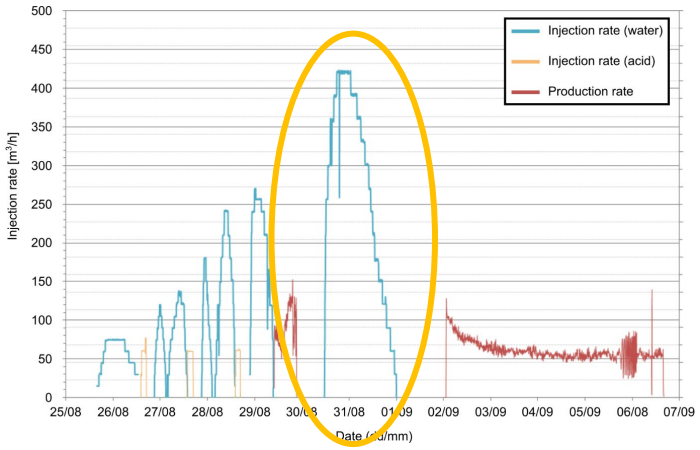
$$D_f \approx l^2/\tau \approx 25 \text{ m/s}^2$$

[Schmittbuhl et al, 2021]

Fluid injections - modelling



Hutka et al, 2025



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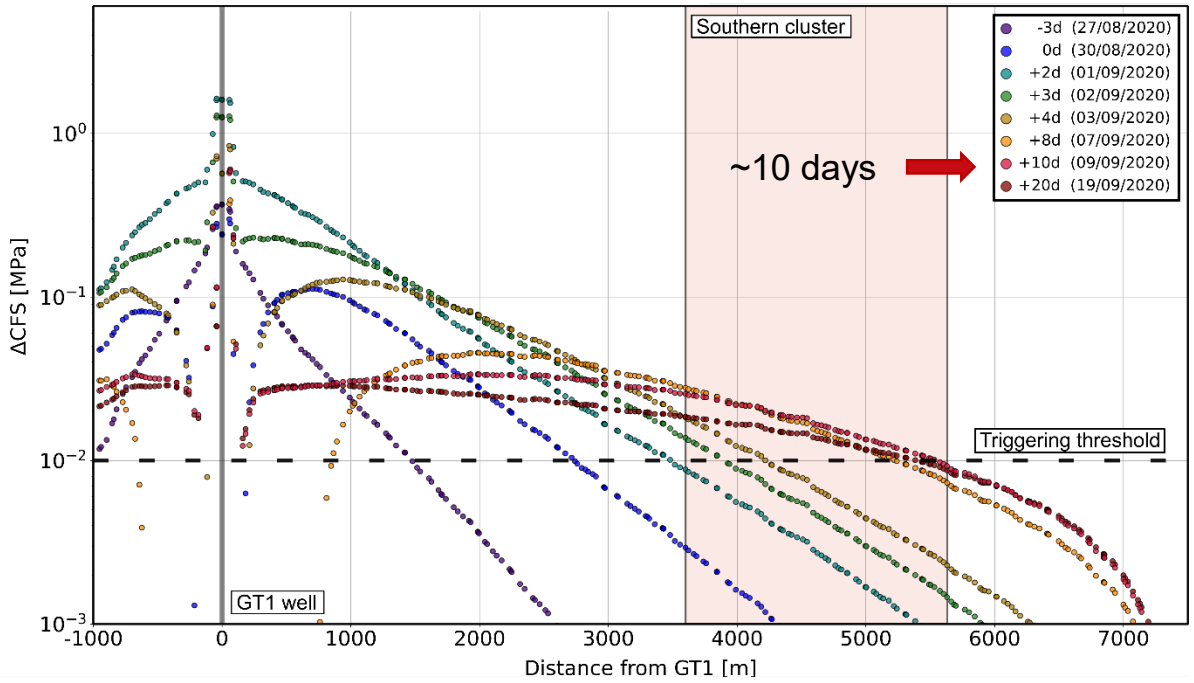

Conclusions

- 4-year sequence of induced seismicity associated with the Vendenheim deep geothermal project, France
- Remotely triggered seismicity (5km from the wells) – delayed max magnitude 6 months after shut-in
- Variations in b-value more spatial than in temporal (inherited structures)
- THM modelling suggests that deep hydro-thermal circulation influences large scale variations in Coulomb stress around the site (along the targeted fault) – also influence of fault geometry (kink)
- THM modelling supports that the pressure diffusion process is responsible for the timing of the triggering
- Implications for hazard assessment and mitigation (importance of exploration)