Utrecht University

7-3-2023

Induced Seismicity and Geothermal Energy Production in the Netherlands

Warming Up PhD's Webinar

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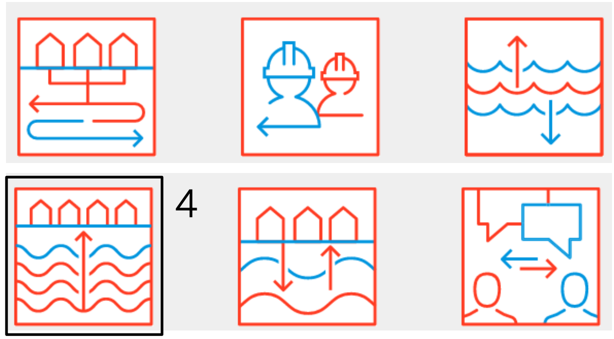
[1] Utrecht University, [2] TNO

Project description

WARMING UP
Innovatief Duurzaam Warmtecollectief



WarmingUP

- National research project, 38 partners
- Accelerate heat transition in the Netherlands
- 25 projects over 6 themes

Theme 4: Geothermal

- Accelerate geothermal development for sustainable heating in urban environments
- 4B: Improve understanding of potential hazards for induced seismicity

Objectives

- Enhance insight in interplay between seismic hazards and geological- and operational conditions (paper 1)
- Develop model capabilities for field-scale evaluation of seismic hazards (paper 2)
- Middenmeer case study, Delft Aardwarmte Project (paper 3)
- Optimization of safe operational window (paper 4)

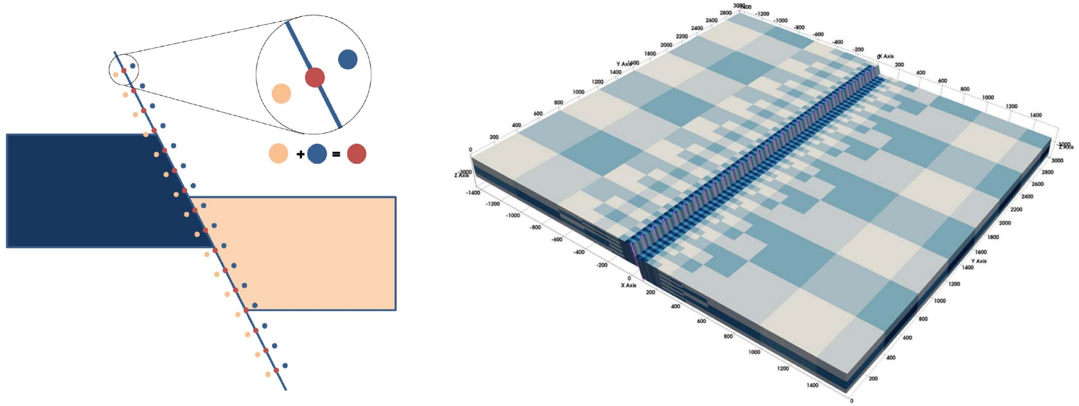
National compilation for subsurface parametrisation

- www.nlog.nl, www.dinoloket.nl
- thermogis.nl

Prediction of subsurface stress response

Modelling approach and workflow:

- Linear elasticity in isotropic layered medium
- Linear thermo-elastic strain: $\varepsilon_{Tz} = \Delta T\alpha \frac{(1+\nu)}{(1-\nu)}$
- Poro-elastic strain: $\varepsilon_{Pz} = \Delta P \frac{(1-\nu-2\nu^2)}{(1-\nu)E}$



From van Wees et al., 2019.

Coupled reservoir flow and thermal simulation (OPM)

MACRIS stress calculation on faults

$$\Delta V = (\varepsilon_{Tz} + \varepsilon_{Pz})\, dV$$

$$\Delta\sigma_{ij} = \lambda\mathcal{E}_{kk}\delta_{ij} + 2G\mathcal{E}_{ij} - 3K\alpha\Delta T\delta_{ij}$$

Uniaxial stress calculation for layered medium

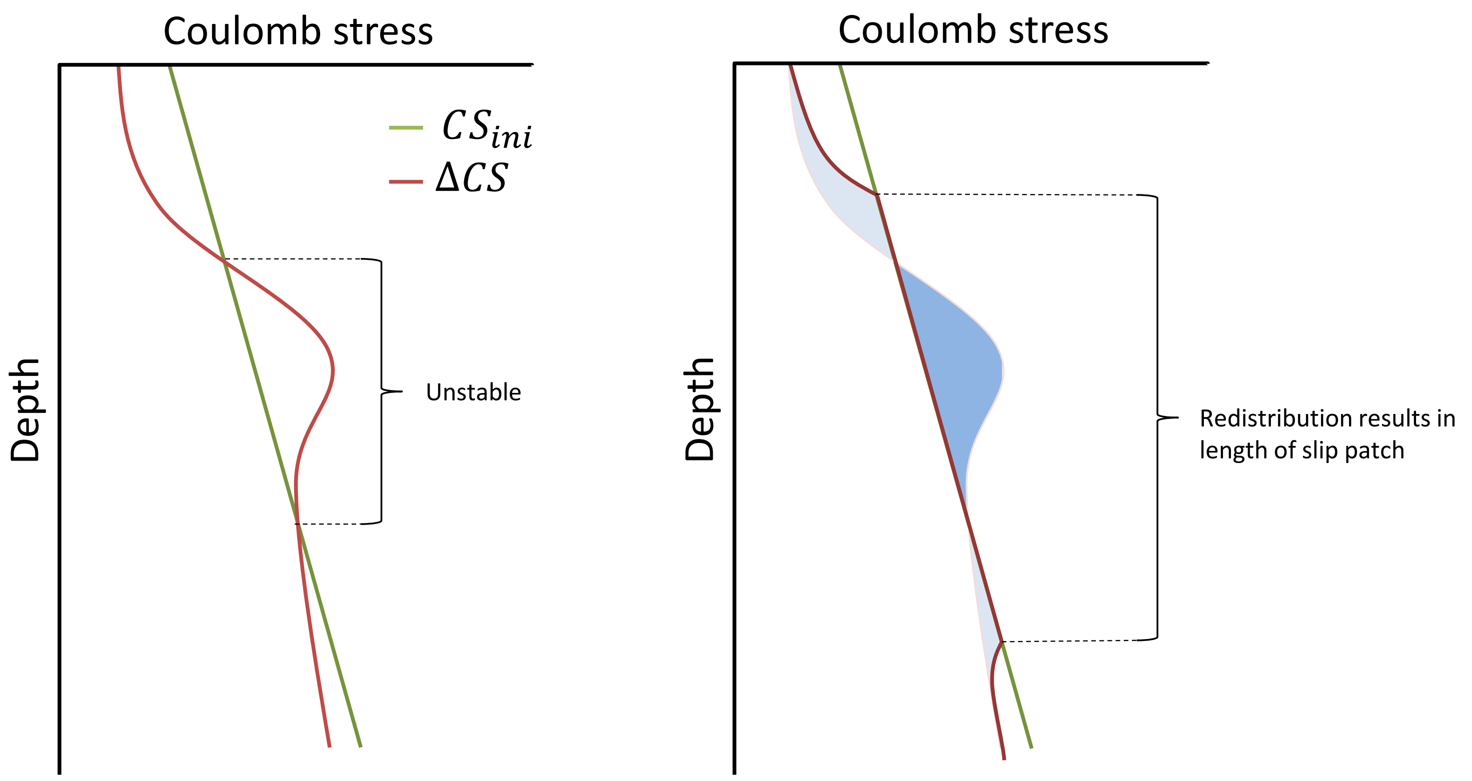
$$\Delta\sigma'_v = -\Delta P$$

$$\Delta\sigma'_{hH} = \Delta\sigma'_{Hh} = (\varepsilon_{Tz} + \varepsilon_{Pz})\frac{E}{(1+\nu)} - \Delta P$$

Seismic hazard assessment

Seismic hazard assessment

- Comparing the change in Coulomb stress to the initial Coulomb stress allows assessment of fault stability along the pillar



From van Wees et al., 2018.

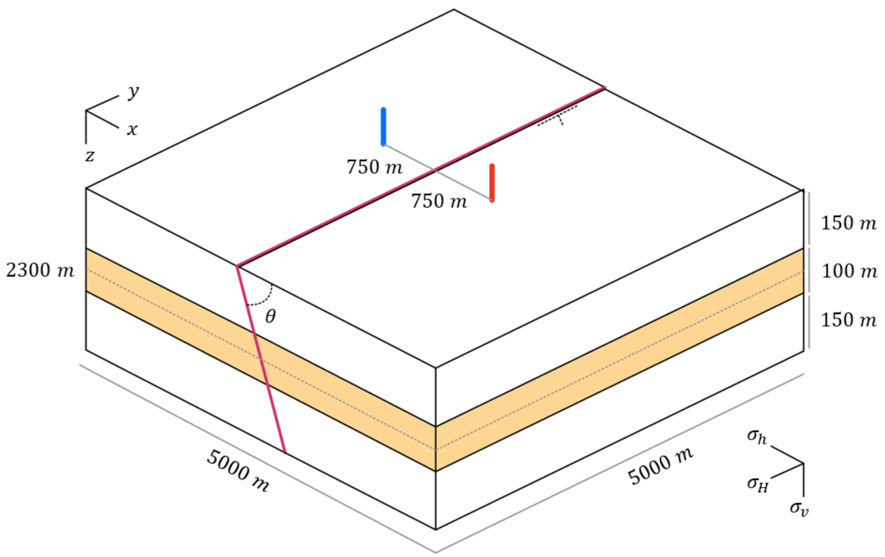
Gutenberg-Richter relationship with constant *b*-value; 38% is released in the largest event (van Wees et al., 2014)

$$M_L = \frac{2}{3}\log\left(\sum \Delta\sigma \frac{l^2}{\sqrt{\pi}} r_p\right) - 6{,}07$$

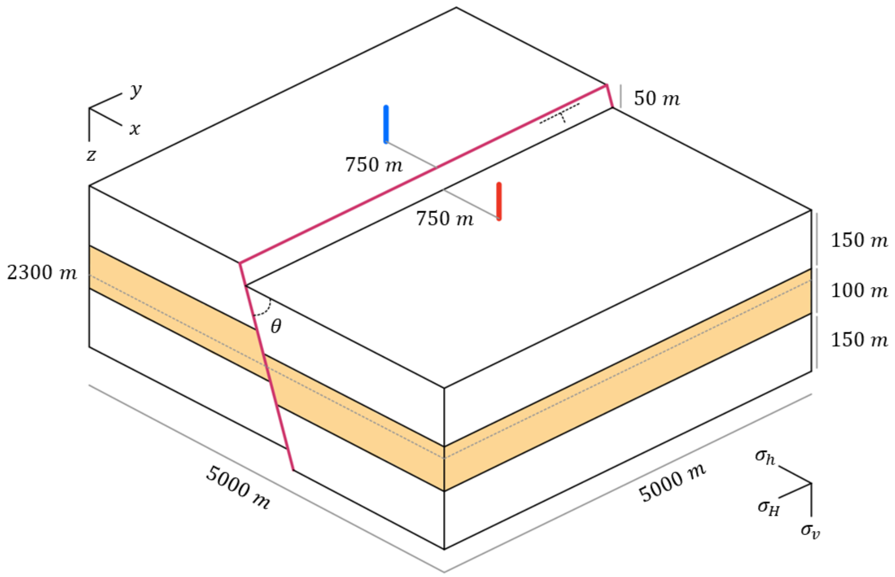
Model description and setup

- Reservoir lifetime 50 years
- Hydrostatic pressure, geothermal gradient of 31 C/km
- 30 C injection temperature
- 500 mD high permeable reservoir zone

- Normal faulting regime
- Fault strike 0, dip 70
- 0,5D offset
- Lithostatic gradient of 22 MPa/km



No fault offset

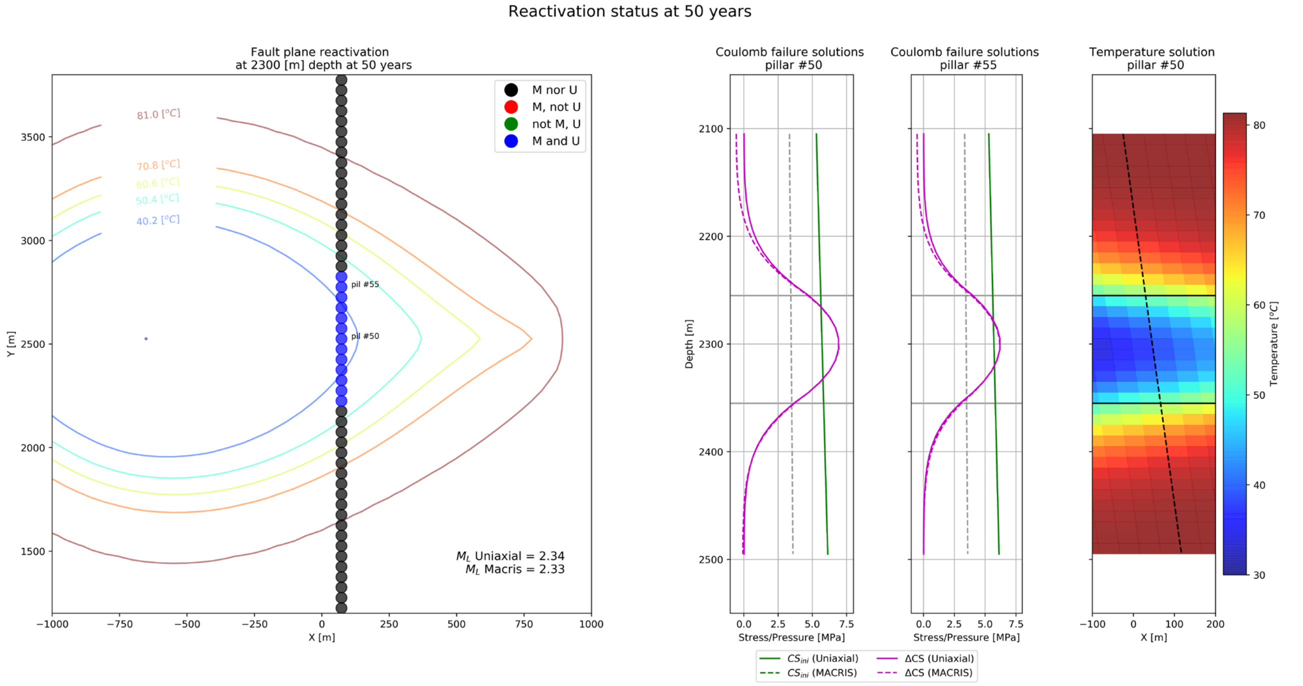


Normal fault offset

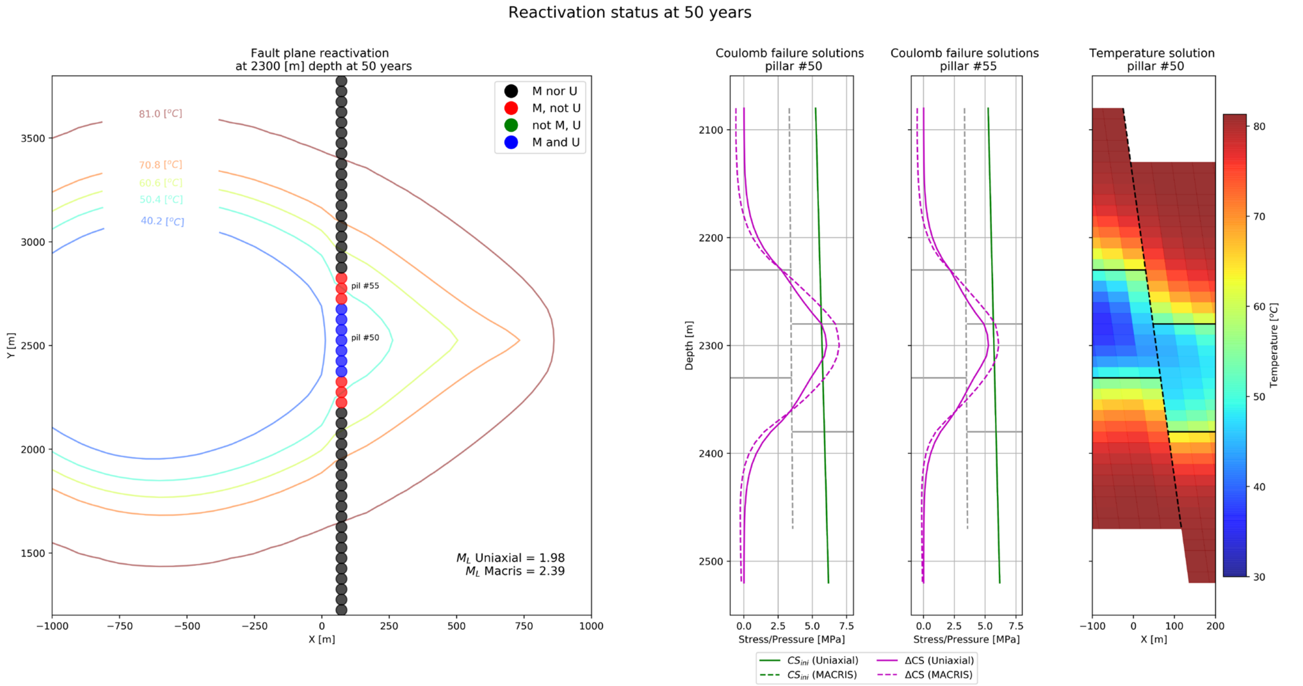
Coulomb failure solution

- Base case scenario

No fault offset



Normal fault offset



Stress arching effects (Wassing et al., 2021)

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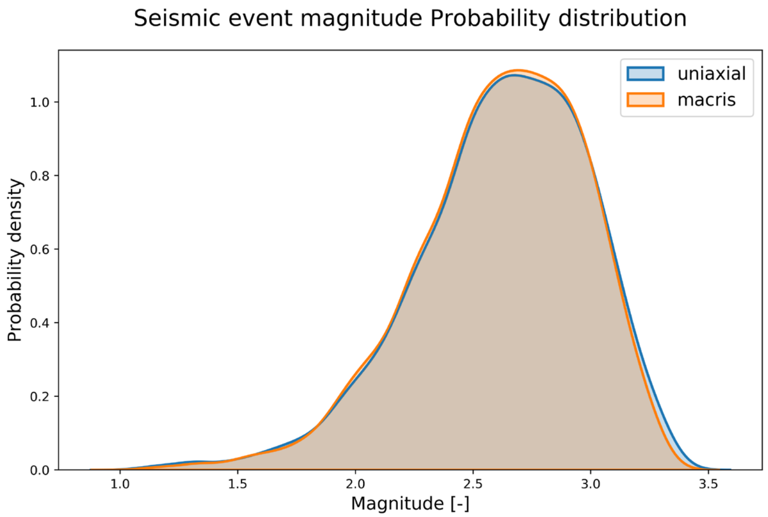
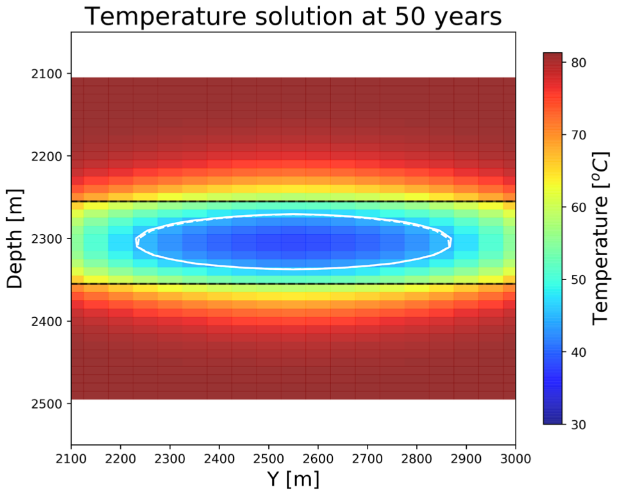
Seismic hazard after 50 years of production

- 10.000 realisations

No fault offset

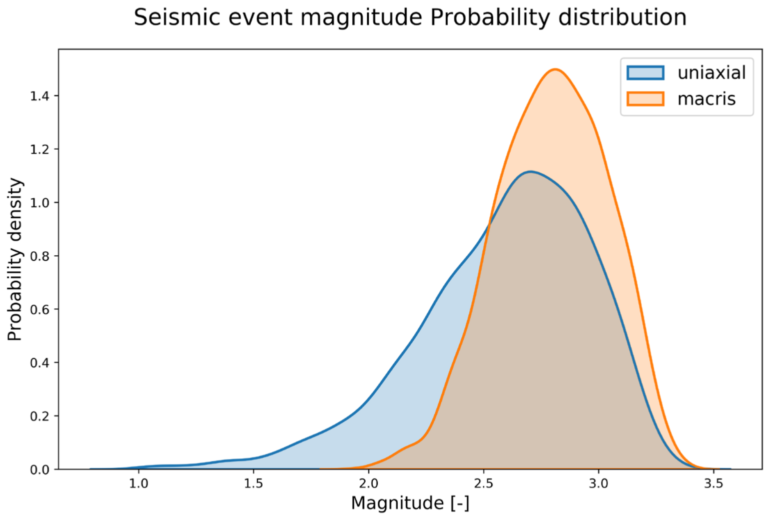
- No seismicity: 57,9%
- M, not U: 0,1%
- Seismic hazard U: 42%
- Seismic hazard M: 42,1%

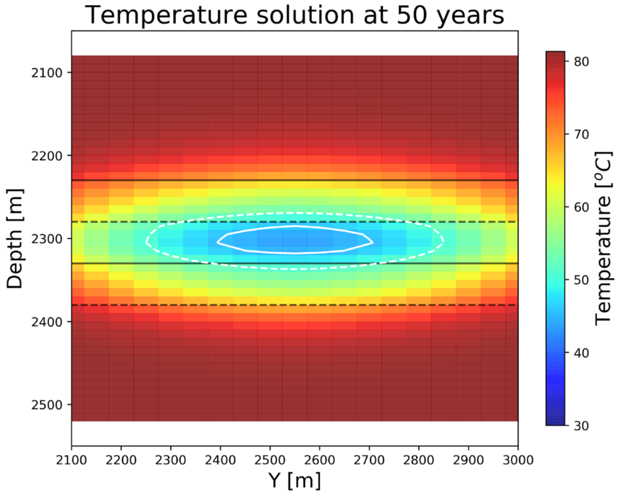




Normal fault offset

- No seismicity: 58,5%
- M, not U: 8,5%
- Seismic hazard U: 33%
- Seismic hazard M: 41,5%



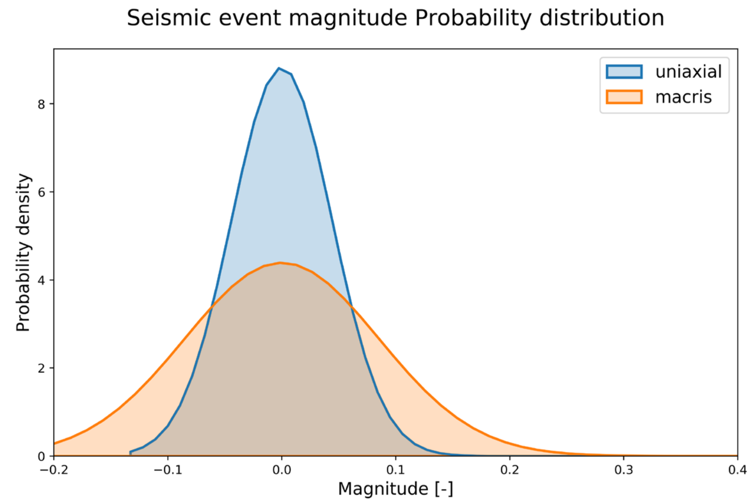


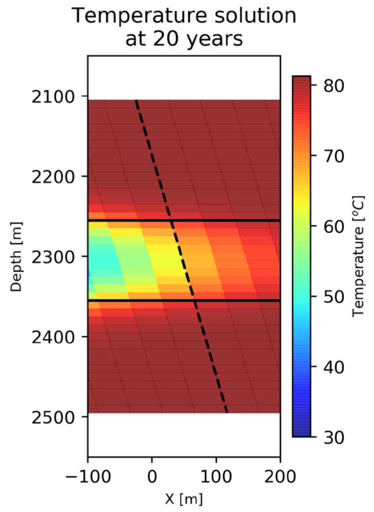
Seismic hazard after 20 years of production

- i.e. when the cold-water front arrives at the fault plane

No fault offset

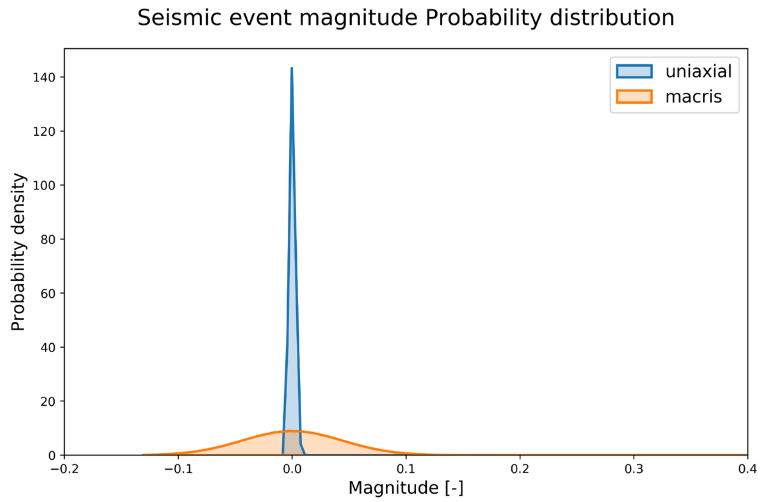
- No seismicity: 95,4%
- M, not U: 2,1%
- Seismic hazard U: 2,5%
- Seismic hazard M: 4,6%

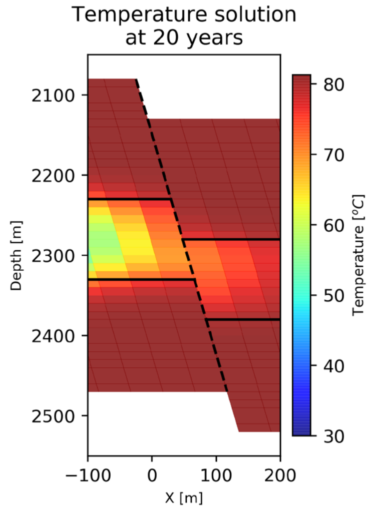




Normal fault offset

- No seismicity: 98,1%
- M, not U: 1,6%
- Seismic hazard U: 0,3%
- Seismic hazard M: 1,9%



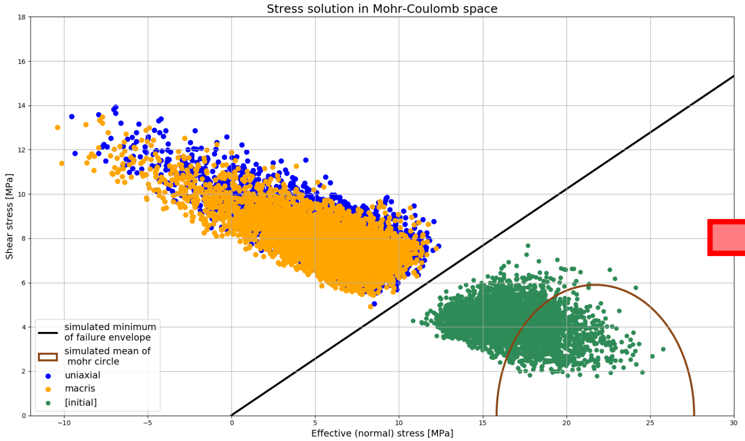


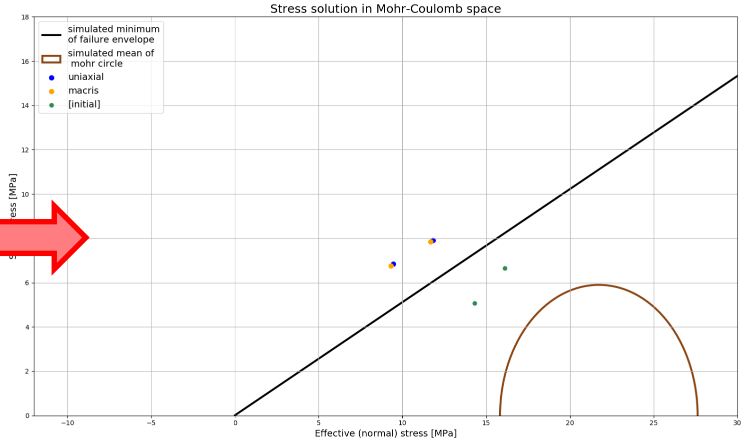
How does this relate to the Dutch subsurface?

- ‘Hot Sedimentary System’ geothermal plays; low α and E; $\Delta T_{max} = 40\ ^{o}C$

No fault offset

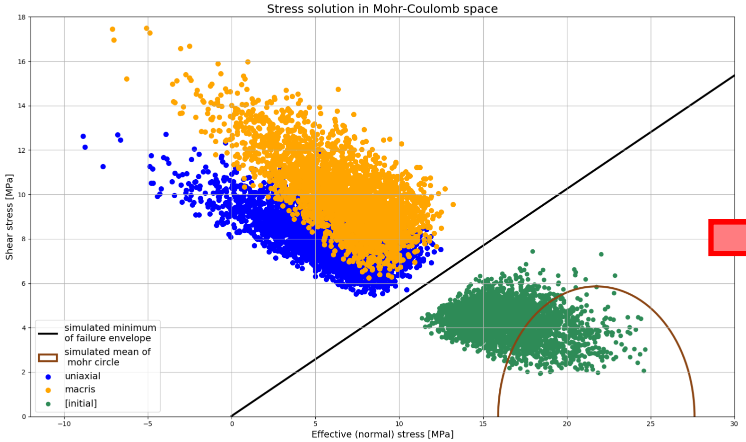
- $M_L \sim 2{,}4$

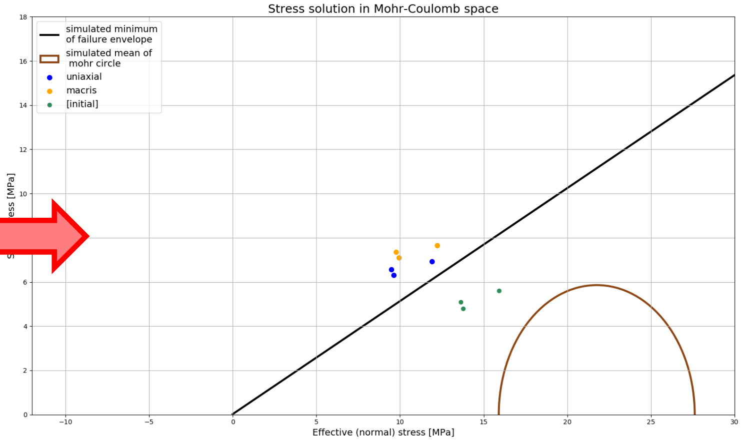




Normal fault offset

- $M_{L,U} \sim 2{,}2$
- $M_{L,M} \sim 2{,}5$

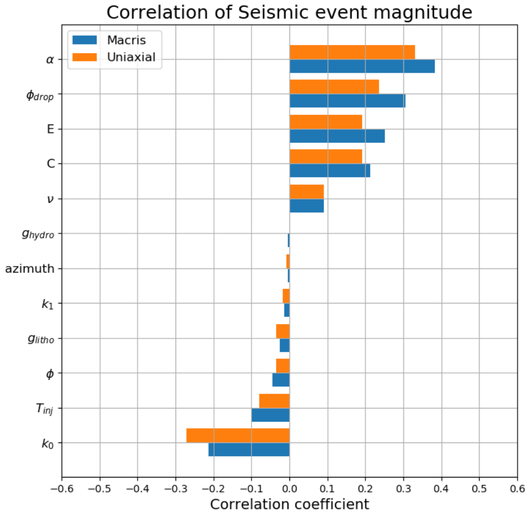


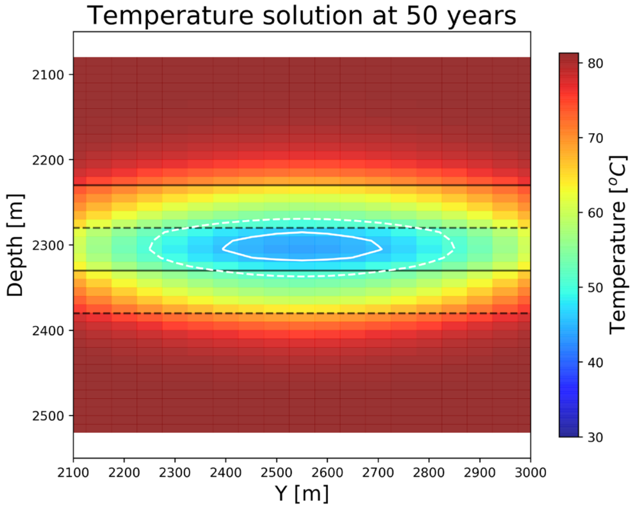


Conclusions of the sensitivity analysis

Modelling results show that the risk of induced seismicity is (mainly) controlled by:

- the thermo-elastic and frictional parameters, and in-situ stress conditions
- the intersection area of cold-water volume with the fault plane
- stress arching effects





Disclaimer

- *The sensitivity analysis is based on a synthetic model. Model parameters are chosen arbitrarily and such that an induced event is likely to occur. Presented results are by no means directly representative of the Dutch subsurface.*

Next steps

2023

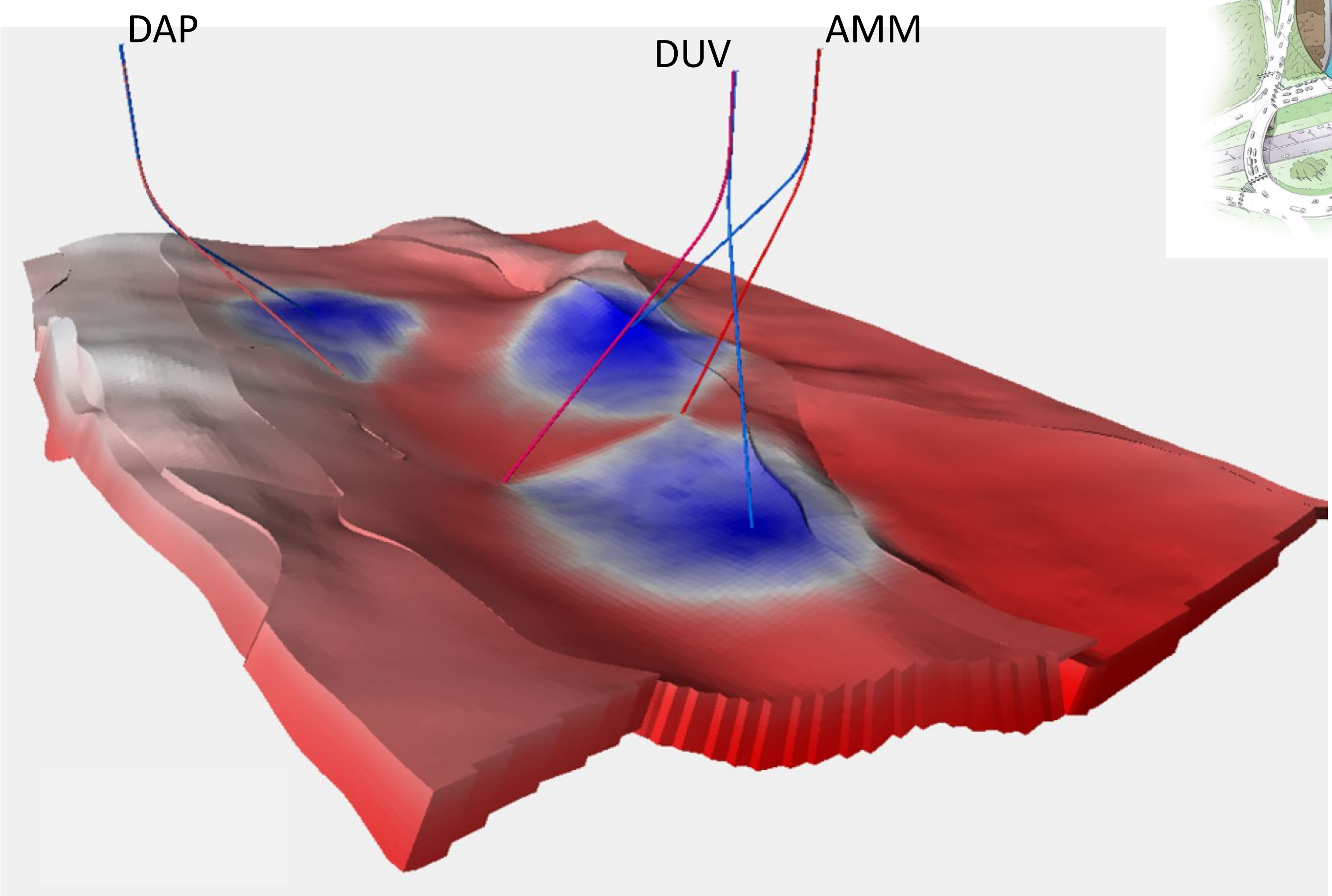
- ➢ Finalizing parameter sensitivity analysis → paper 1
- ➢ Development of new 3D modelling approach encompassing arching effect → paper 2
- ➢ Application of new modelling approach on two case studies → paper 3a+3b
    - o Middenmeer agriport
    - o Delft Aardwarmte Project

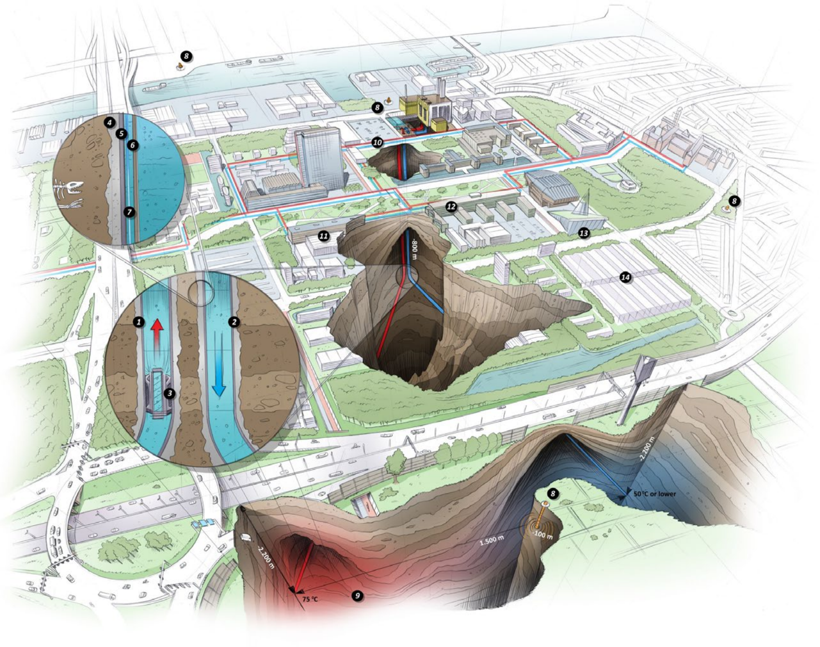
2024

- ➢ Extension of modelling workflow to include: → paper 4
    - o Well design
    - o Determination of operational safety window
    - o Artificial intelligence concepts
- ➢ Finalising PhD project (writing dissertation; PhD defence)

NL case study: Delft Aardwarmte Project

- DAP well location near fault(s)
- 3 doublets located in single fault block





From: https://delta.tudelft.nl

From Reinhard, 2019

Thank you!

Back-up slides

NL case study: Delft Aardwarmte Project

- DAP well location near fault(s)
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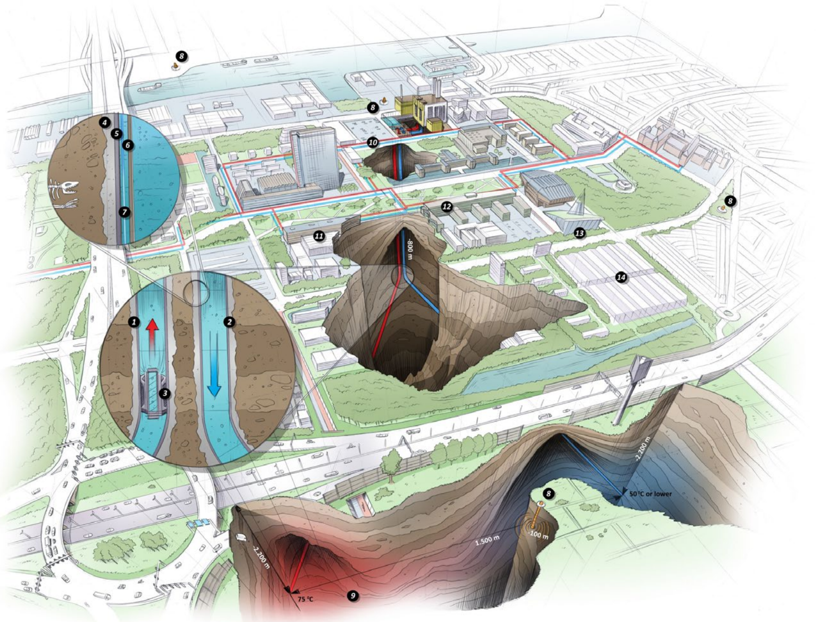
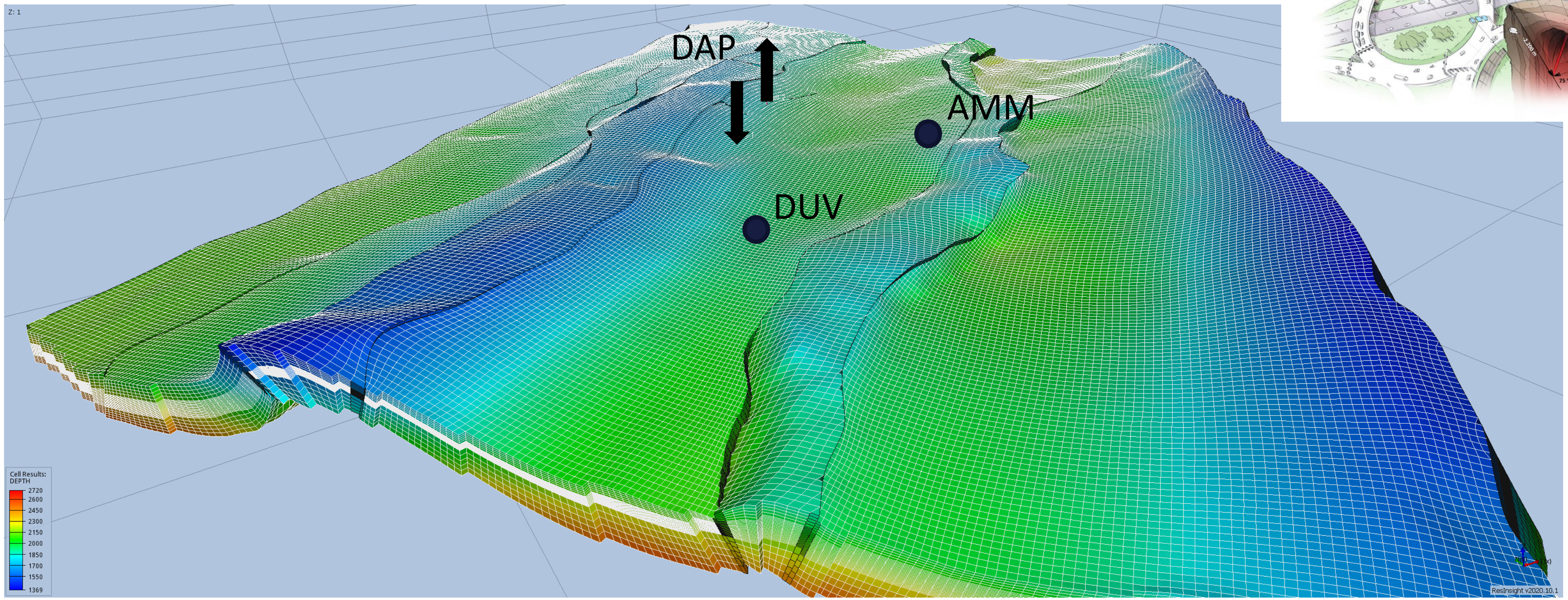
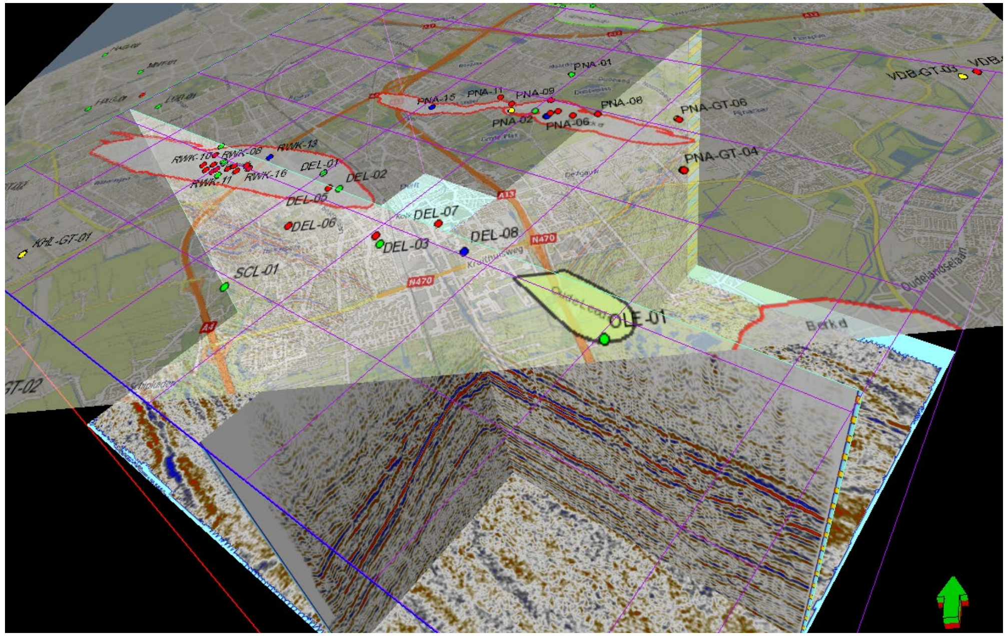
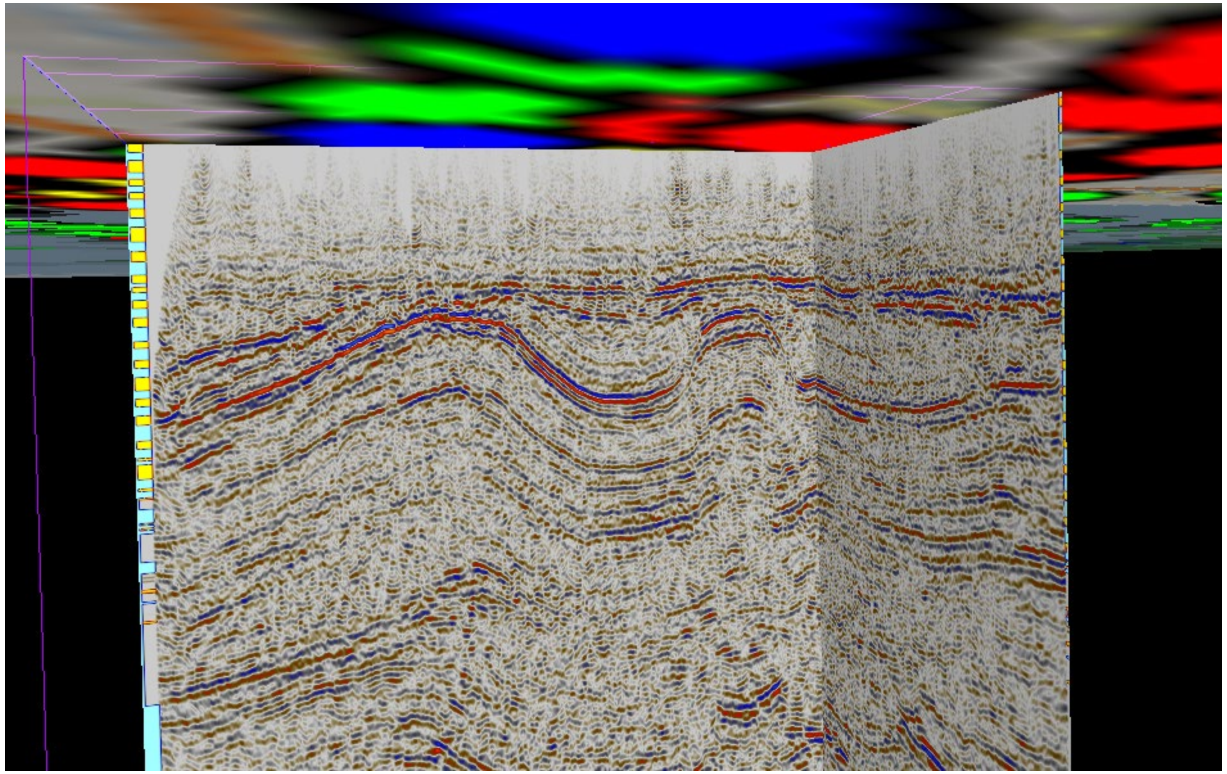
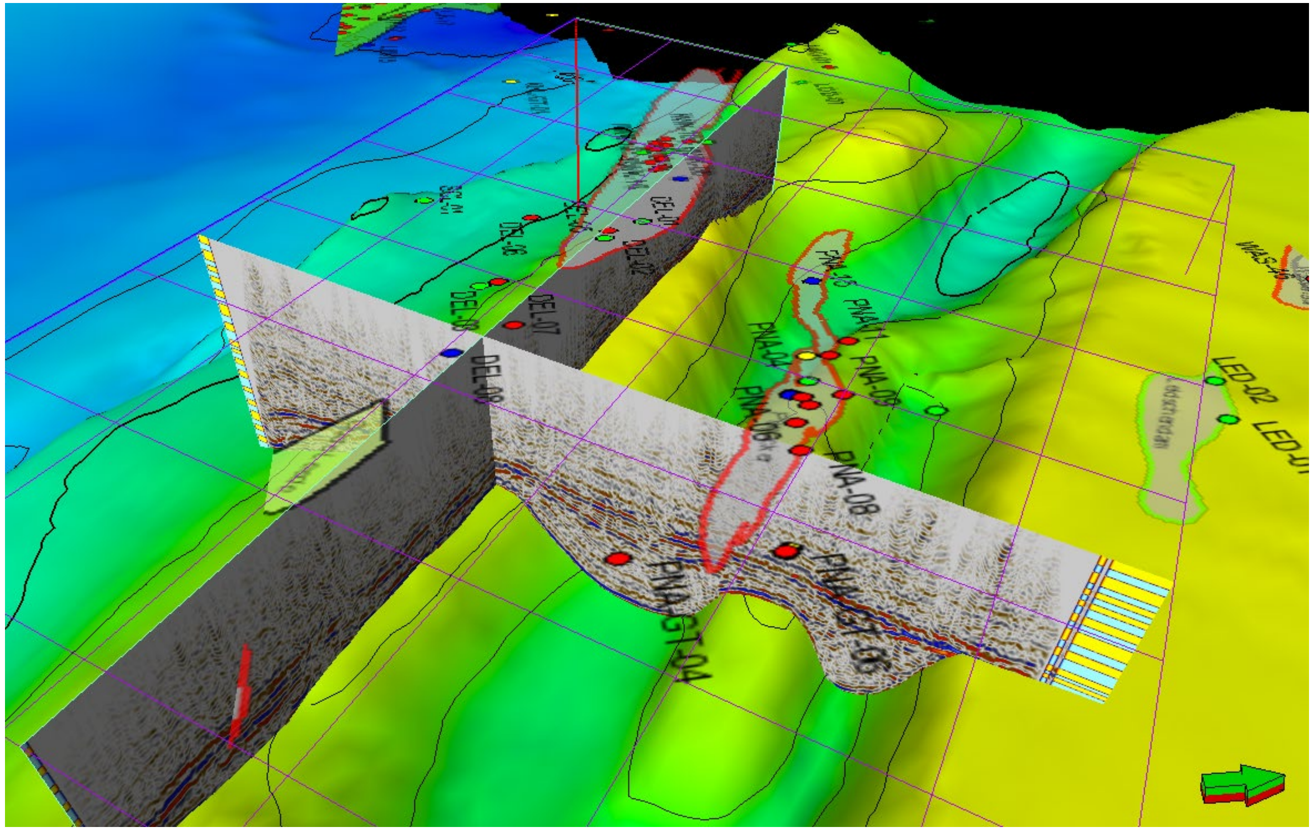




TU Delft campus

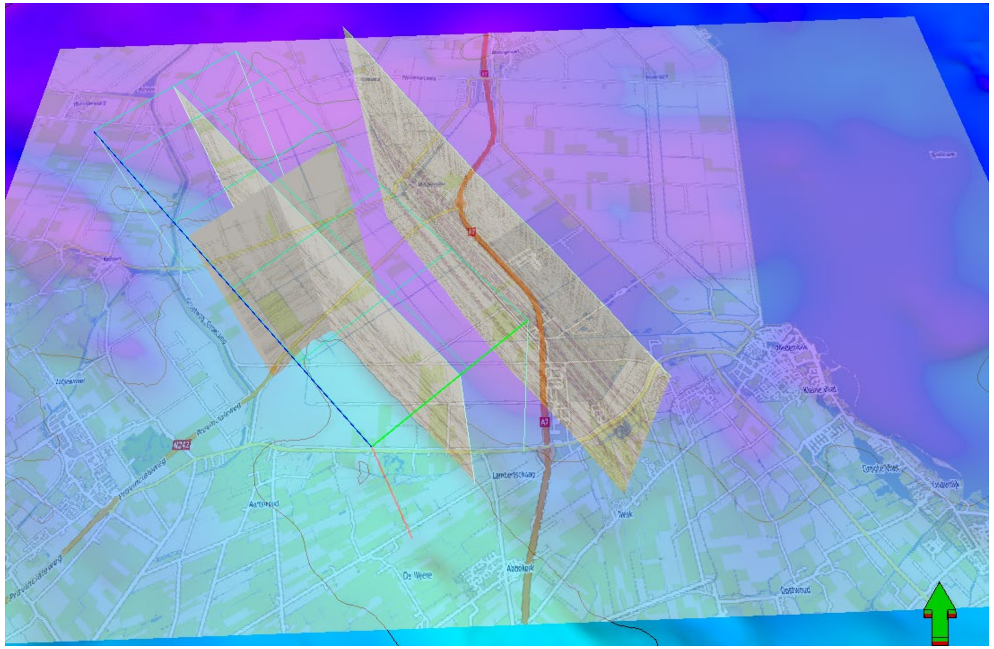


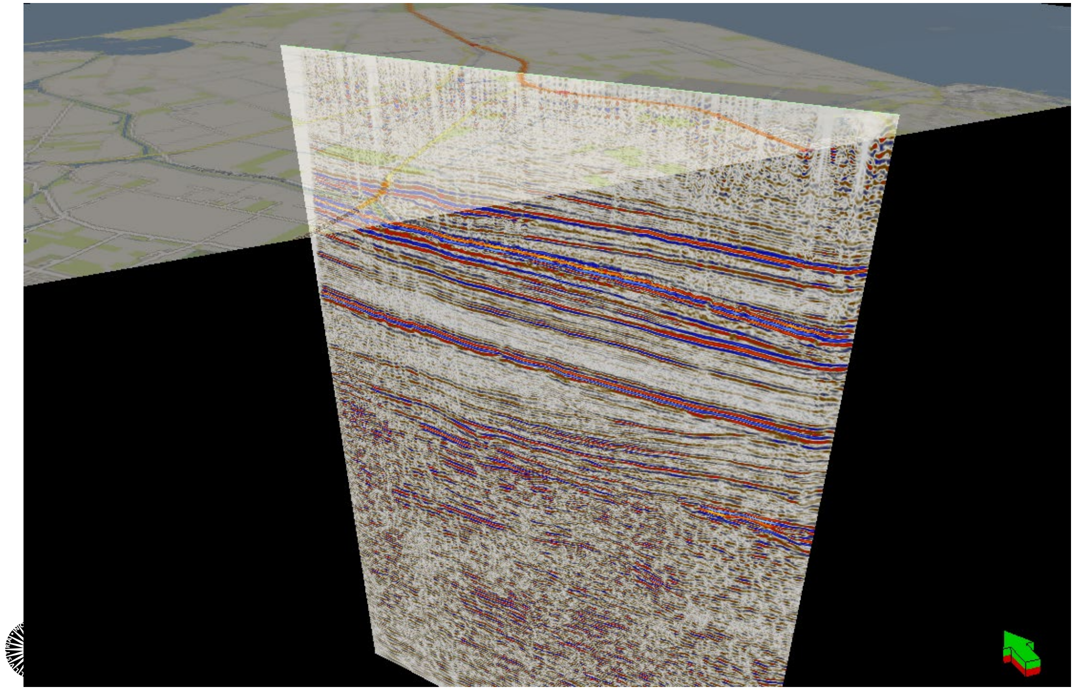


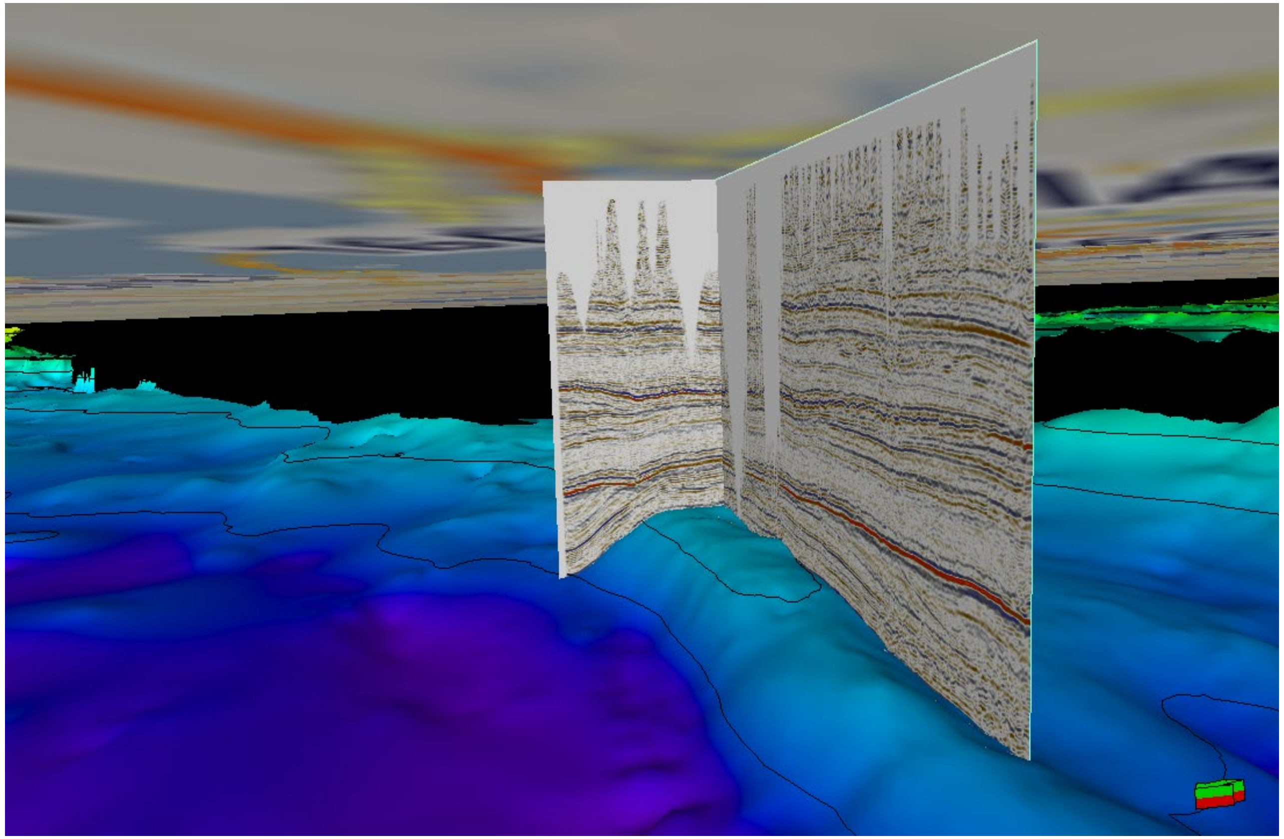


- DAP well location: intersection of the two seismic lines
- Note the structural deformation of the deeper subsurface, situated in the West-Netherlands Basin

Middenmeer







Activities

PhD courses:

- Reservoir Geomechanics, Python and Java
- Responsible Conduct of Research (*completed*)
- Start-to-Teach (*completed*)

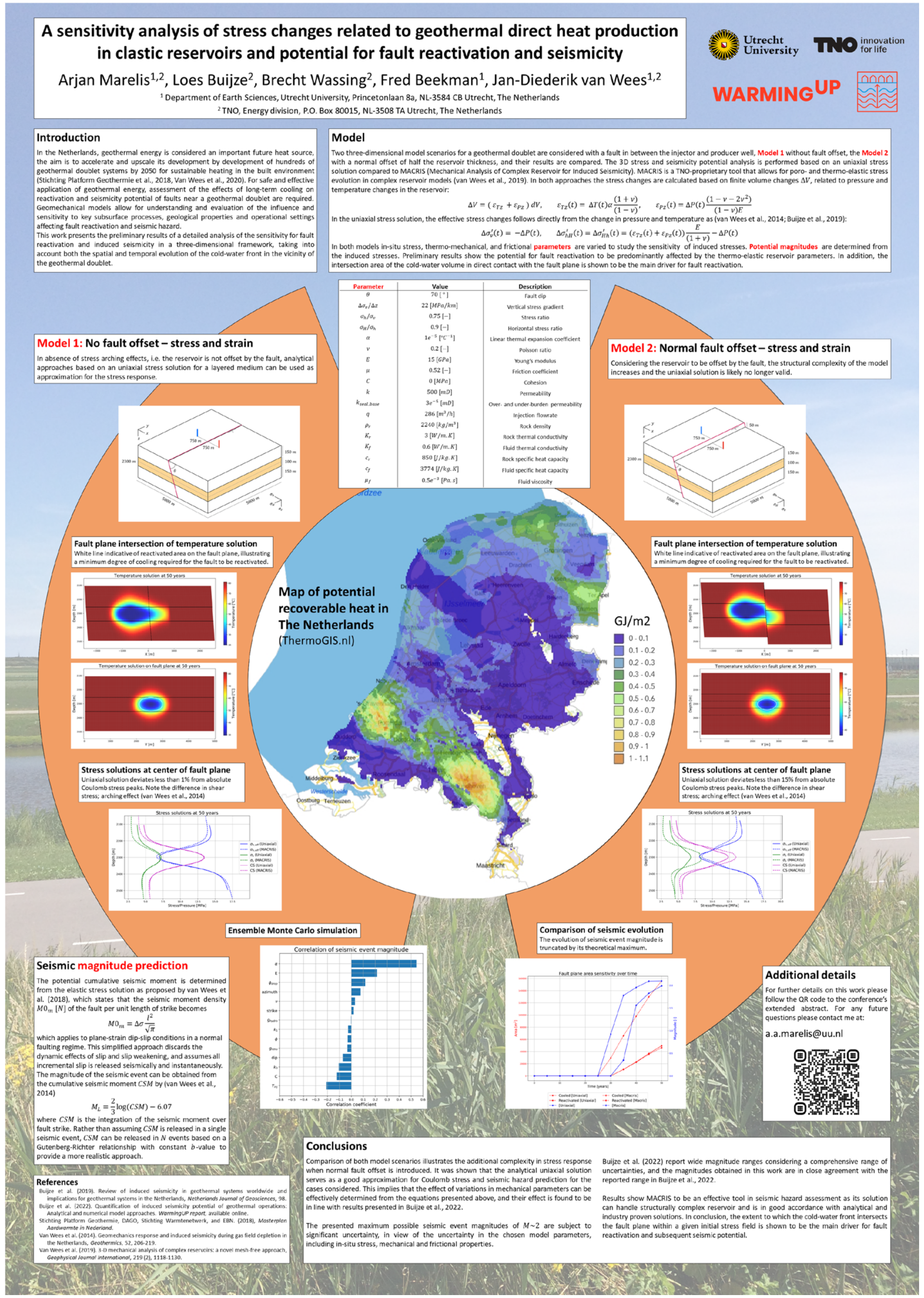
Teaching assistant:

- Unconventional and Geothermal Resources
- Programming and Modelling

Conferences:

- 2021: NAC, EU Geothermal PhD Days, EGU General Assembly and GeoMod
- October 2022: European Geothermal Conference, poster presentation (*A sensitivity analysis of stress changes related to geothermal direct heat production in clastic reservoirs and potential for fault reactivation and seismicity*)

- March 2023: NacGEO (presenting)
- April 2023 : EGU23 (presenting)
- December 2023: AGU23 (presenting)



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