Simulation of the transport phenomena in the Horstberg geothermal system

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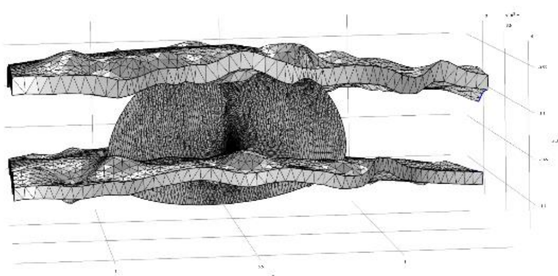
Motivation

- The Horstberg geothermal reservoir in the North German Basin (80 km north of Hannover)

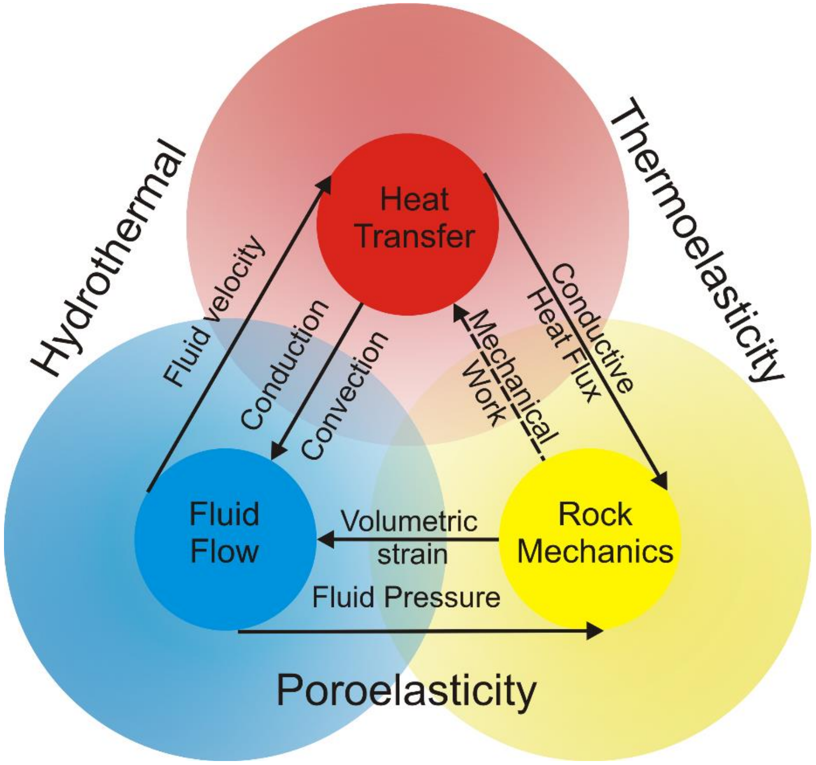
- Reservoir depth: 3650 m TVD
- Reservoir temperature: 144 °C
- Reservoir pressure: 584 bar
- Shmin: 650 to 680 bar



- An induced hydraulic fracture hydraulically connects two sandstone layers
- Area of induced fracture: 196,000 [m^2]

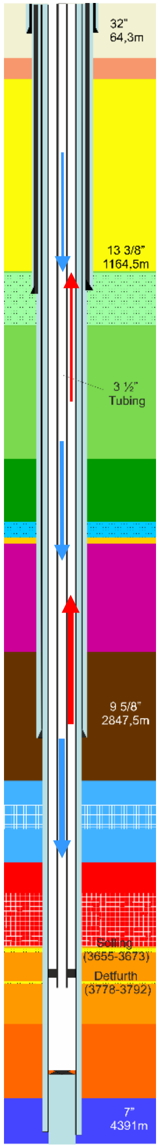
Research Question

- How to simulate transport phenomena in a geothermal system

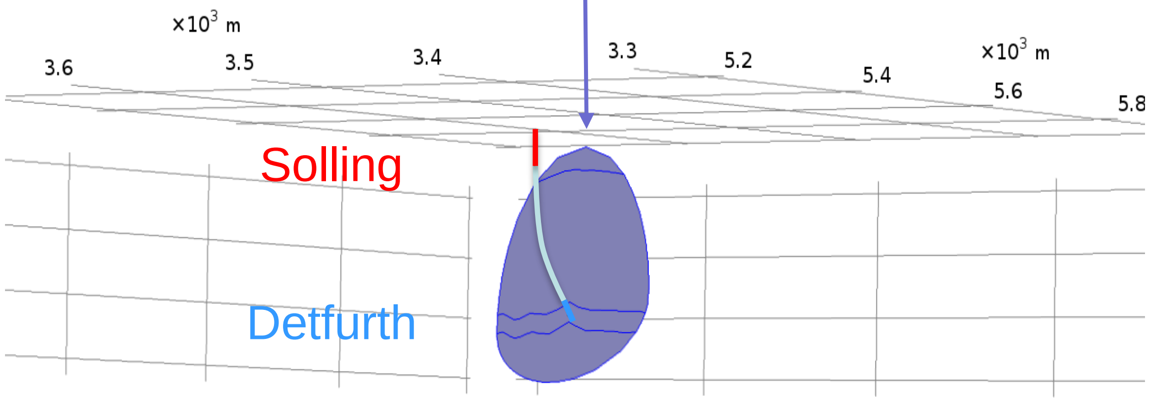


(Hassanzadegan, 2012 PhD thesis)

Horstberg Wellbore



- A monoborehole concept was applied in a multilayered sandstone reservoir
- Production through annulus from Solling Formation and injection through tubing into Detfurth Formation
- Induced hydraulic fracture



Borehole Model

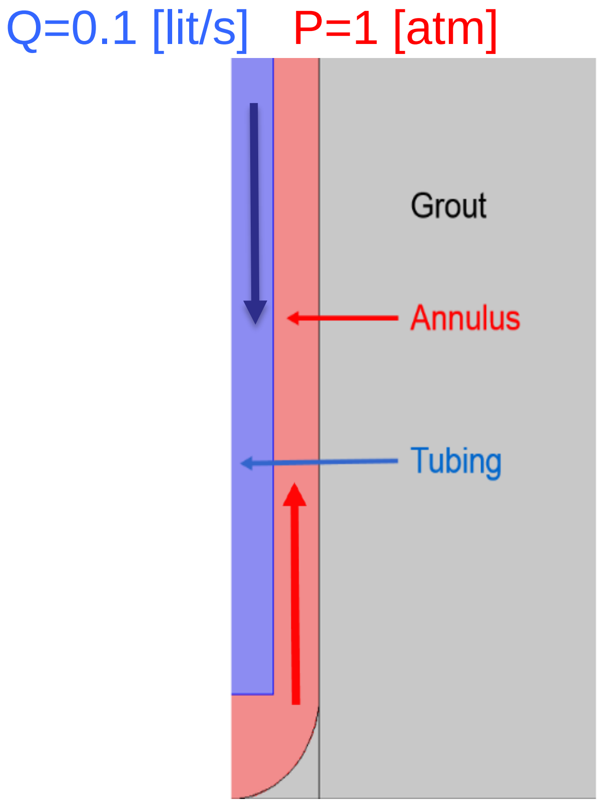
- Laminar Flow : velocity and pressure fields

- Conservation of mass

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \boldsymbol{u}) = 0$$

- Conservation of momentum

$$\rho \frac{\partial \boldsymbol{u}}{\partial t} + \rho(\boldsymbol{u}.\nabla)\boldsymbol{u} = \nabla \cdot [-p\boldsymbol{I} + \tau]$$

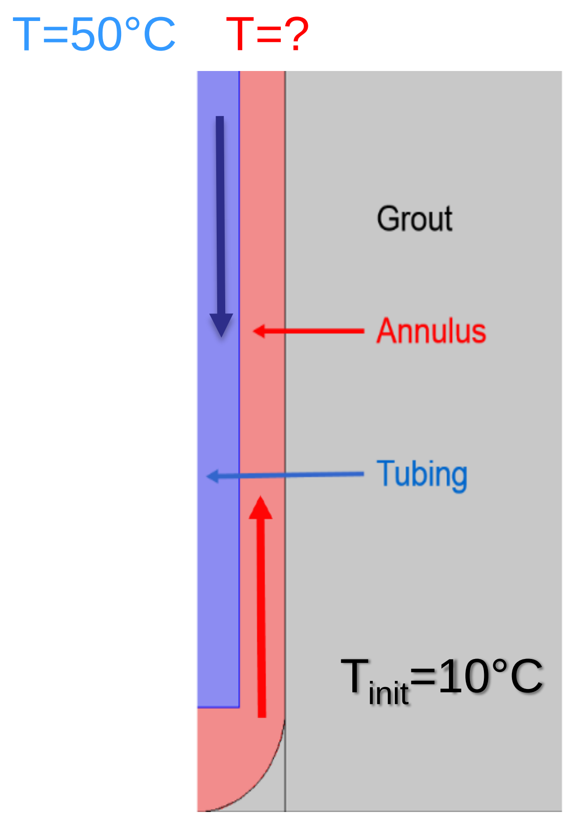


Borehole Model

- Heat Transfer in Fluid: temperature field

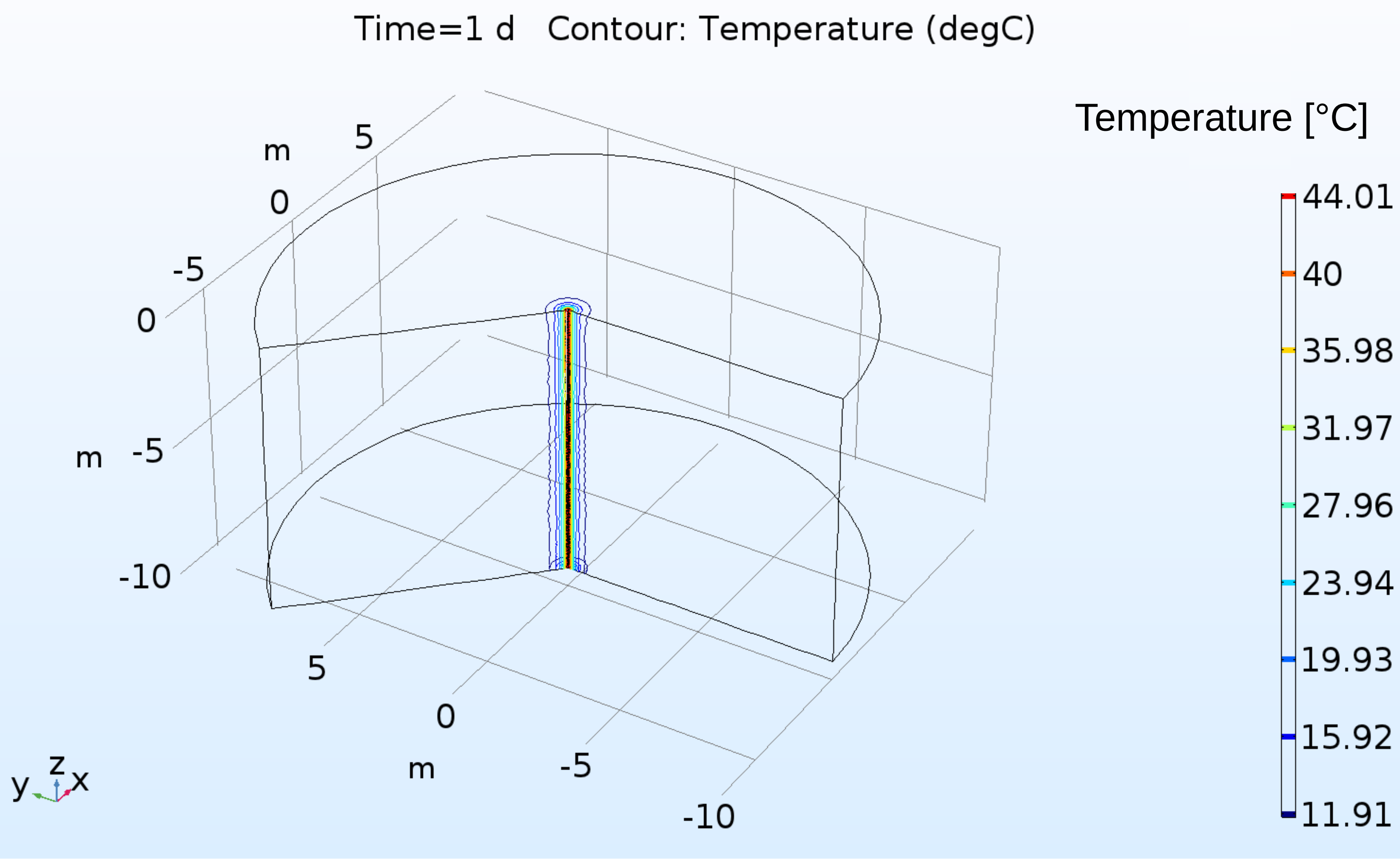
$$\rho c_p \frac{\partial T}{\partial t} + \rho c_p \boldsymbol{u} \cdot \nabla T = \nabla . \left(\lambda_f \nabla T \right) + \boldsymbol{\tau} : \nabla \boldsymbol{u}$$

T	Temperature
C_p	Heat capacity
λ	Thermal conductivity
$\boldsymbol{u}$	fluid velocity vector
ρ	density
τ	viscous stress tensor

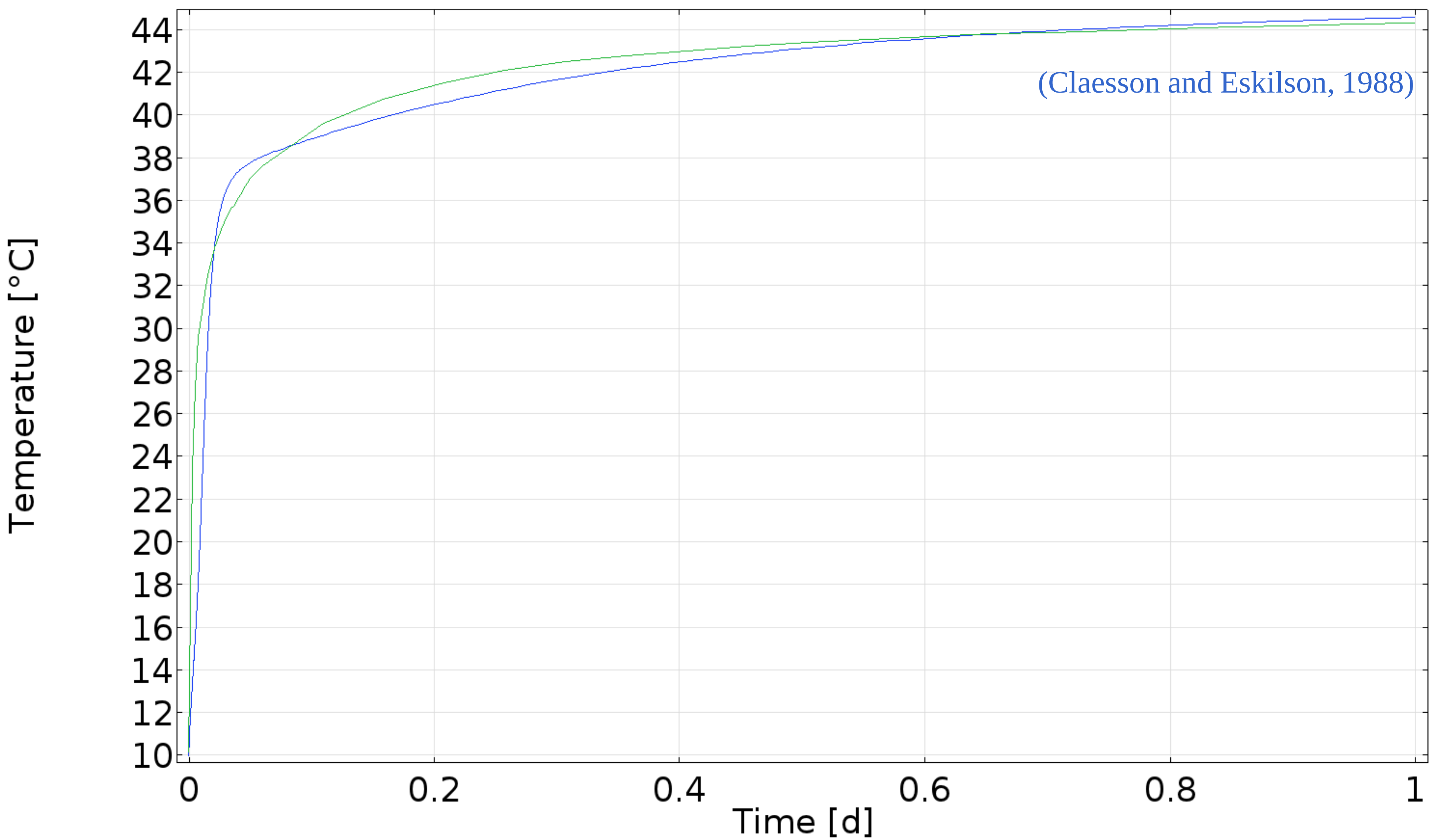


- The fluid flow was first solved in a stationary study and the resulting pressure and velocity fields were used in heat transfer study

Verification Model
Axial Symmetry



Verification Model



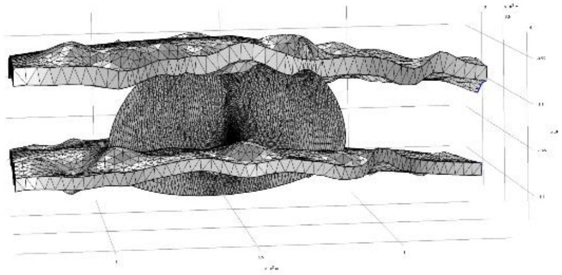
Transient Poroelasticity

- Transient poroelastic equation:

$$\frac{\rho}{M}\frac{\partial p}{\partial t} + \nabla \cdot \rho\left[-\frac{k}{\mu}(\nabla p + \rho g z)\right] = -\rho\alpha\frac{\partial \varepsilon_v}{\partial t}$$

(Biot, 1962)

Storage Mass conservation Sink/Source term



σ	Stress
M	Biot Modulus
ζ	Fluid mass content increment
C	Stiffness matrix
α	Biot coefficient ($0 \leq \alpha \leq 1$)
ε	Bulk strain
ε_v	Volumetric strain
I	Unit tensor
p	Pore pressure

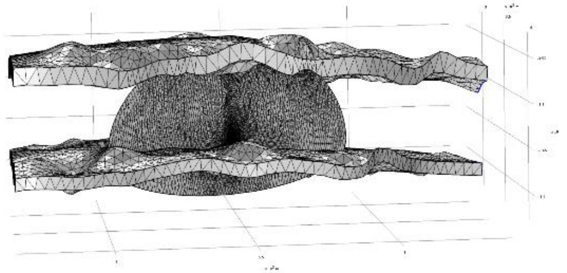
- Constitutive poroelastic equations:

$$\boldsymbol{\sigma} = \mathbf{C}\varepsilon - \alpha p \mathbf{I}$$

$$p = M(\zeta - \alpha\varepsilon_v)$$

Heat transfer in porous media and fracture

- heat transfer in porous media



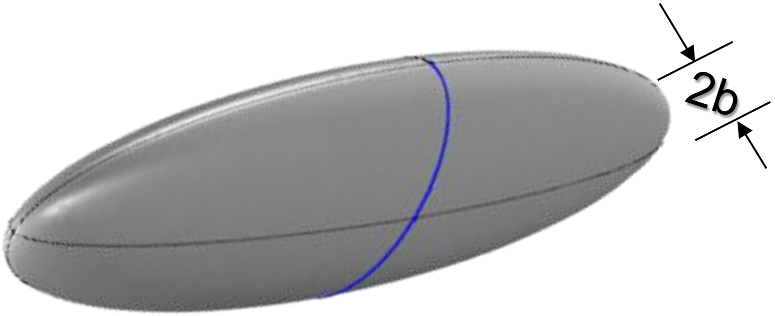
$$(\rho\, C_p)_{eff}\frac{\partial T}{\partial t} + \nabla\cdot(\rho C_p \boldsymbol{u} T) + \nabla\cdot\boldsymbol{q} = Q_h$$

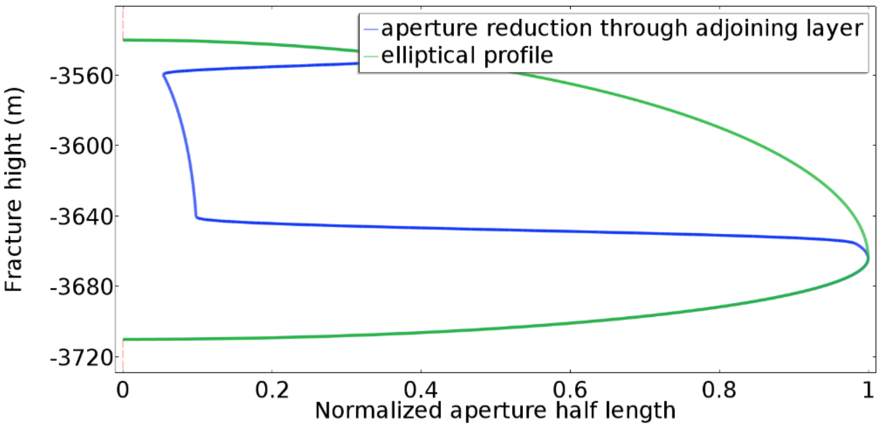
- heat transfer in a fracture is similar to porous media

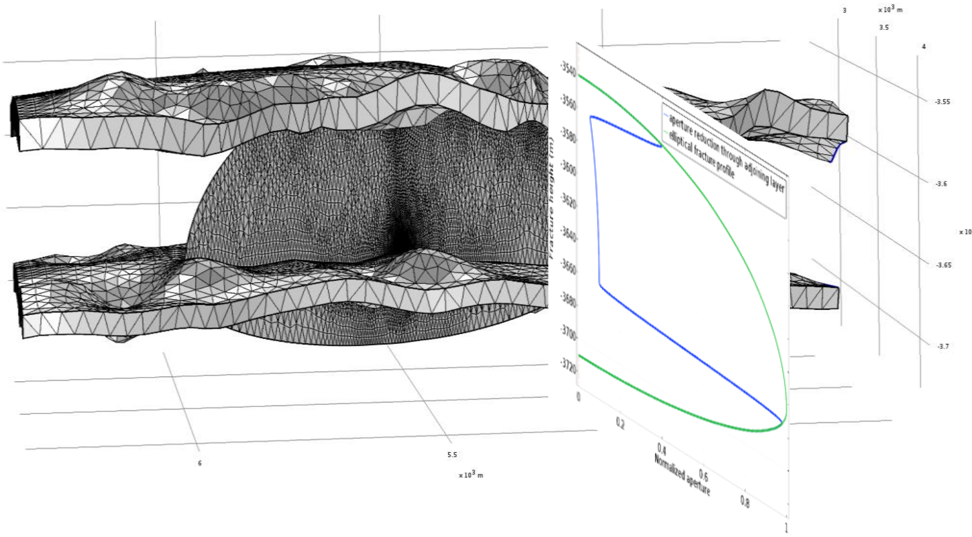
$$b(\rho\, C_p)_{eff}\frac{\partial T}{\partial t} + \nabla_{\mathrm{t}}\cdot(b\rho C_p \boldsymbol{u_t} T) + \nabla_{\mathrm{t}}\cdot\boldsymbol{q_{fr}} = bQ_h$$

Fracture Dimensions

- Fracture half length : 500 m
- Fracture height : 175 m
- Fracture half aperture (b): 0.0001 m







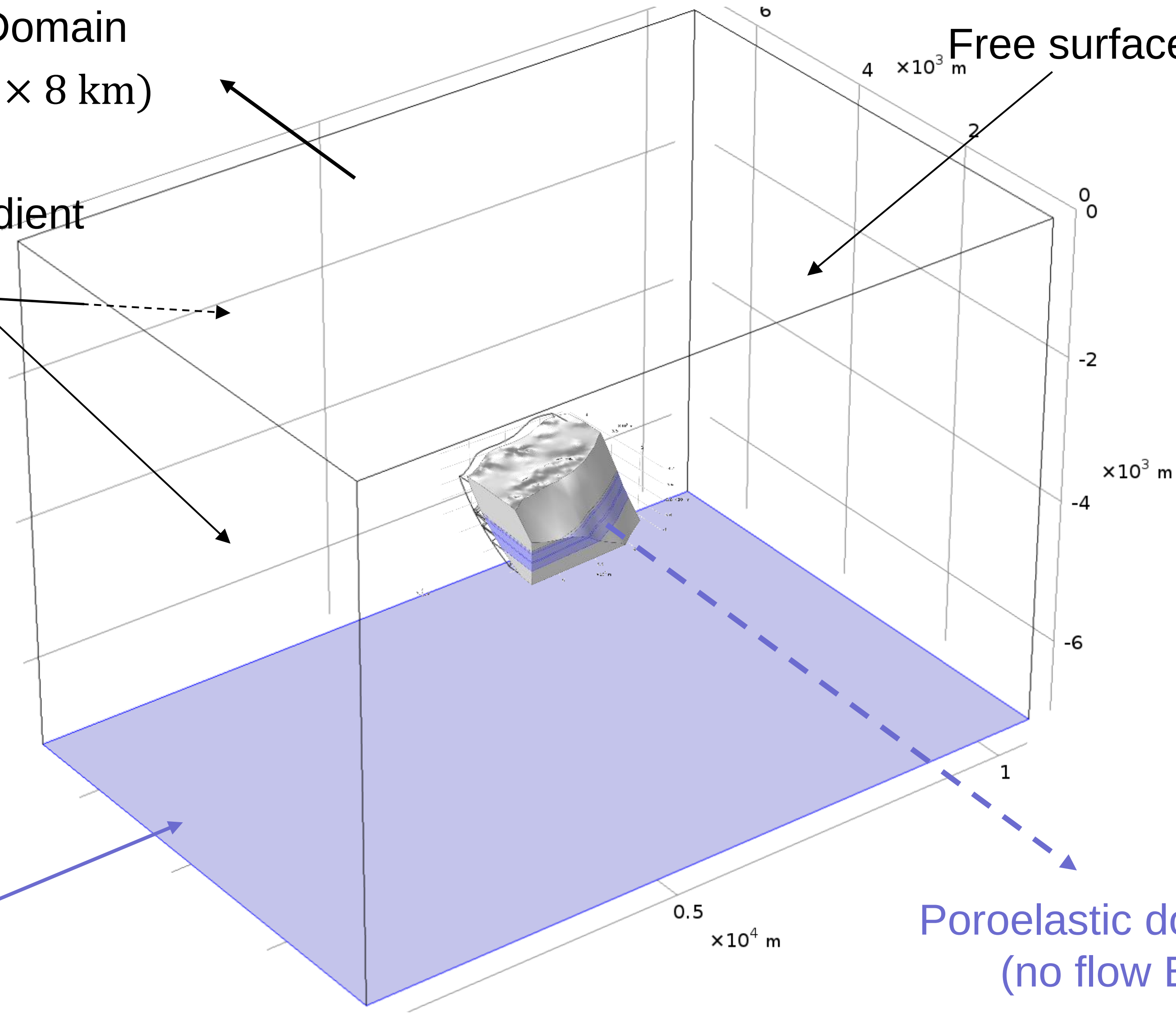
Base Scenario

Mechanical Domain

(10 km × 7 km × 8 km)

Lithostatic pressure gradient

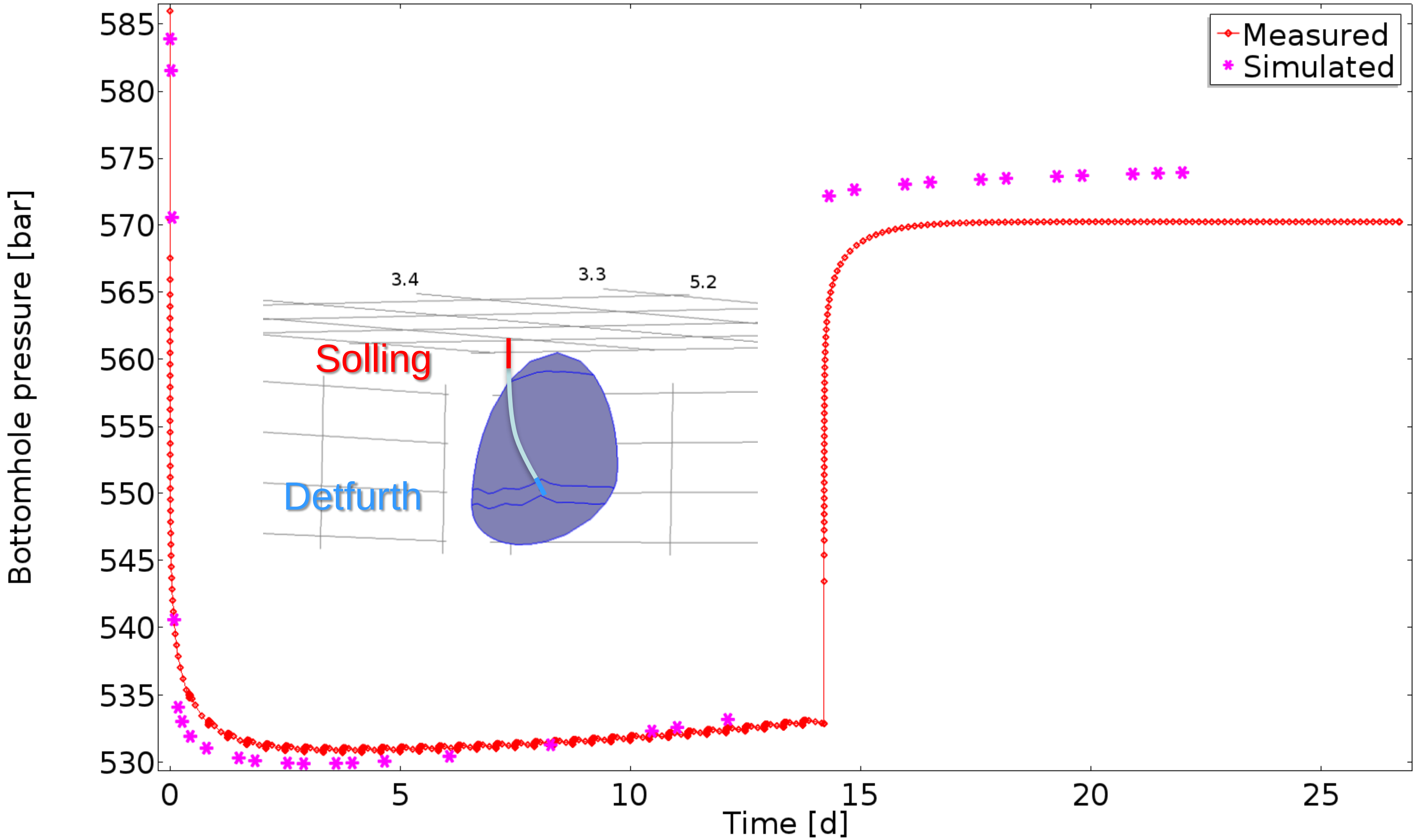
Free surface



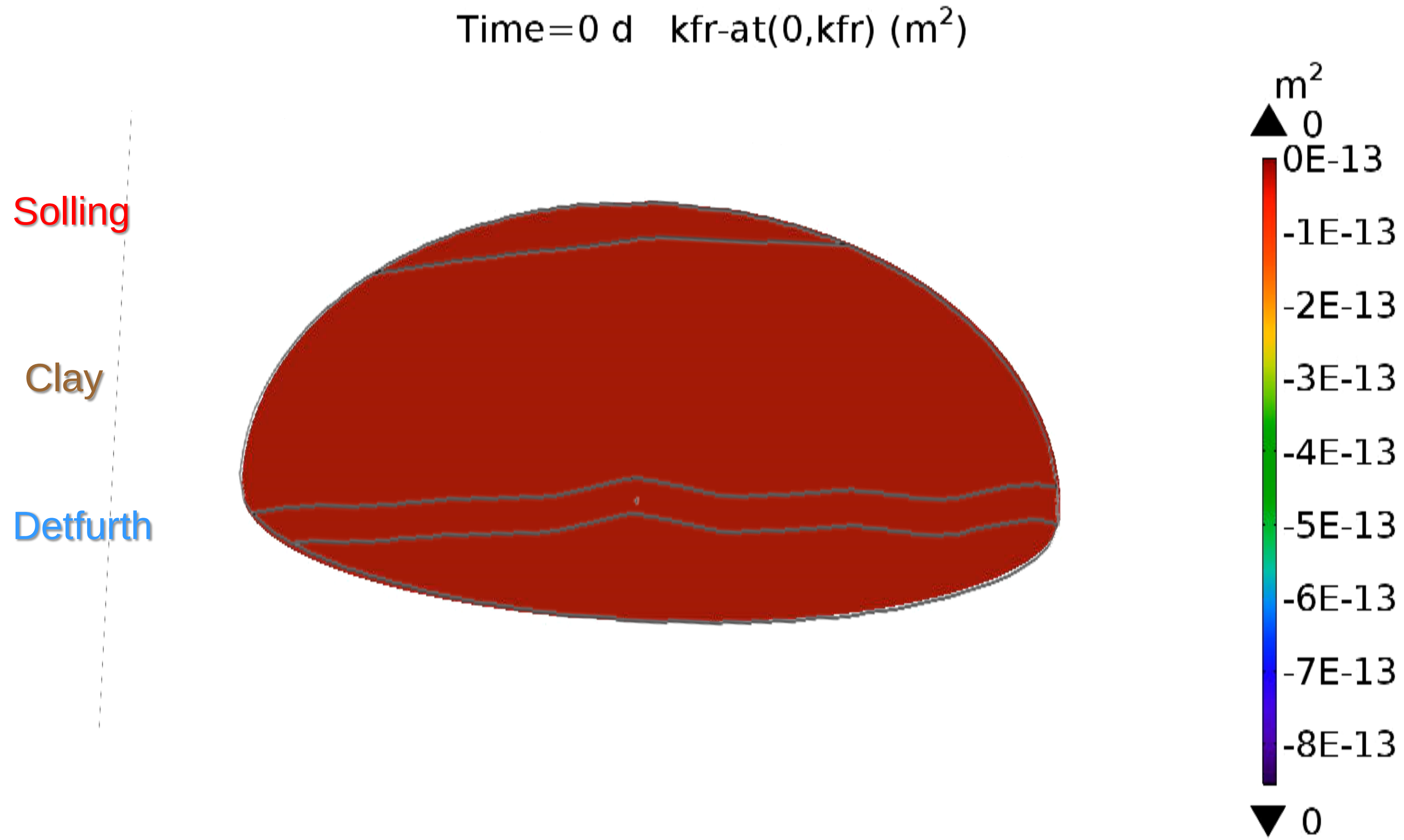
Roller

Poroelastic domain (no flow BC)

Pressure Transient Test - Solling
Hydraulic Calibration of the Model



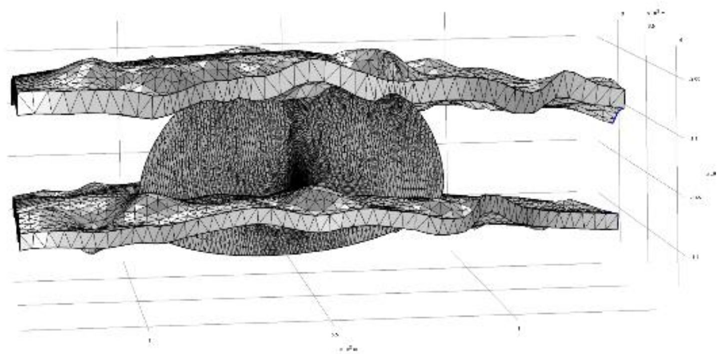
Fracture Permeability Changes



Summary and Outlook

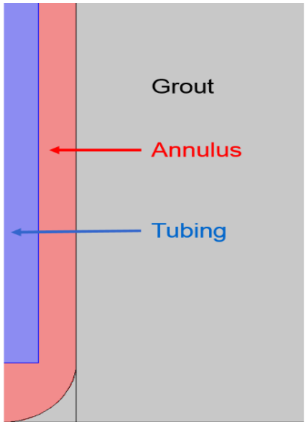
- Comsol Multiphysics is applied to simulate transport phenomena in borehole and reservoir models.

- The coupling aims at transferring data between two models while updating boundary conditions as follow:



Update BCS:
Production pressure and Temperature

Update Injection presure and temperature



Thank you,

Questions?

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