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Numerical Analysis of the integrity of potential host rocks – modelling thermo-hydro-mechanical processes in the containment providing rock zone

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Numerical Analysis on integrity of potential host rocks

Modelling thermo-hydro-mechanical processes in the containment providing rock zone in crystalline rock

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safeND
Interdisciplinary research symposium on the safety of nuclear disposal practices

BGR Bundesanstalt für Geowissenschaften und Rohstoffe

Nuclear repositories in Germany

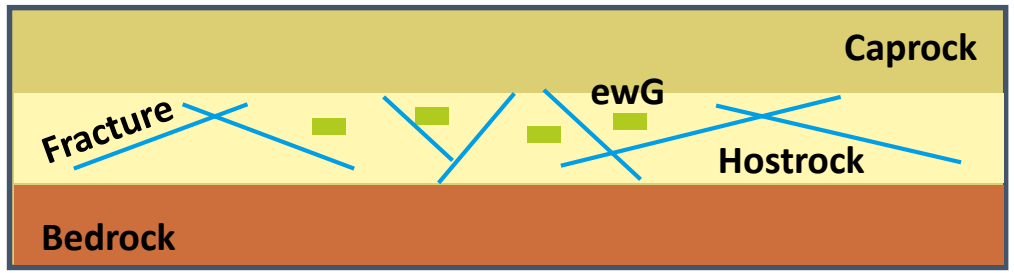
Clay, salt and **crystalline rock** are investigated as potentially suitable host

Framework of the joined project **Christa II** which focused on the development of a safety and verification concept for a repository containing heat-generating radioactive waste in **crystalline rock** using generic numeric models

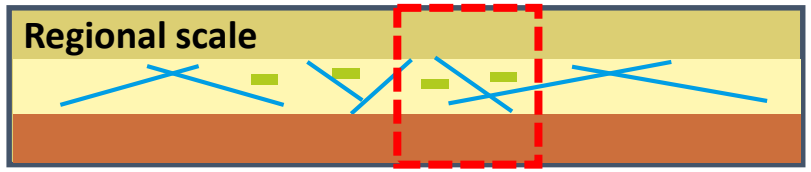
- Project partners: BGE TECHNOLOGY GmbH, GRS global research for safety

The repository system type investigated was the „**multiple ewG**“

- ewG (einschlusswirksamer Gebirgsbereich): containment providing rock zone

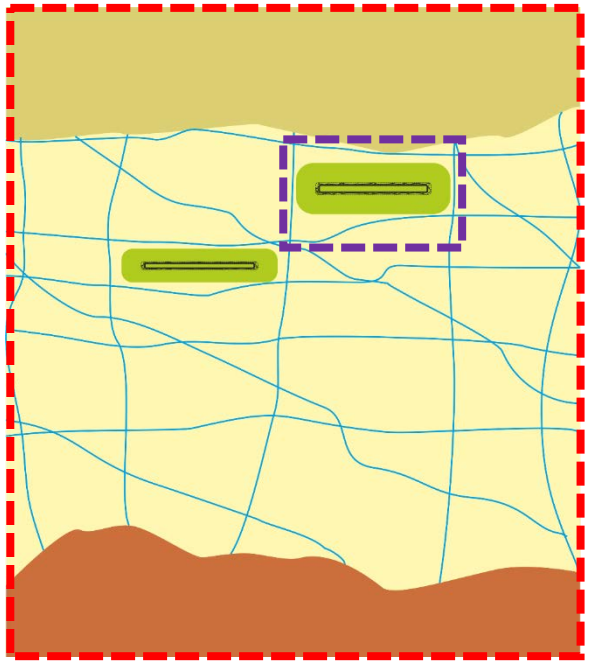


Repository system multiple „ewG“ crystalline rock as barrier

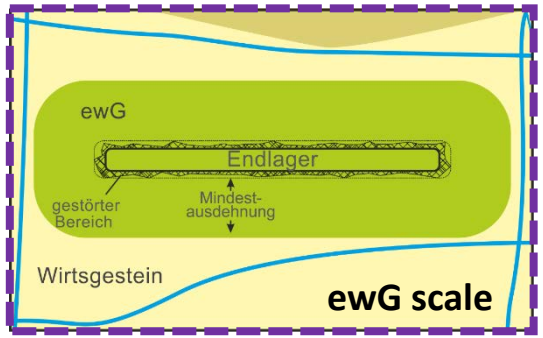


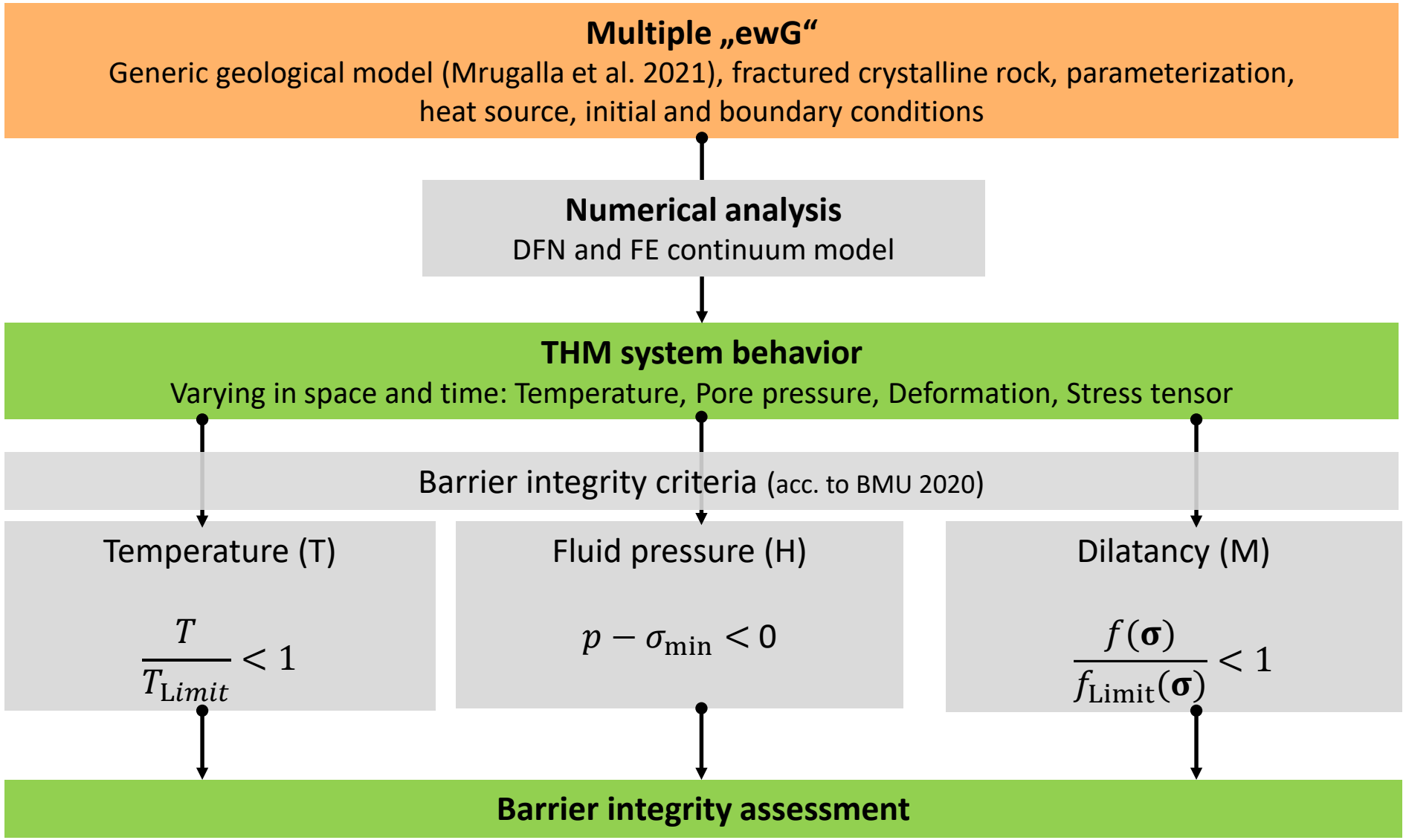
Crystalline rock is generally intersected by fractures. **Fractures** in crystalline rock usually dominate the hydraulic behavior and therefore also transport mechanisms.

Hydraulically active **fractures** represent a preferential flow path, so radionuclides could be rapidly transported here. Therefore, hydraulically active **fractures** should not be present in the ewG. Unfractured areas (km-scale) are not expected in the crystalline rock, therefore the concept "multiple ewG“ is used.



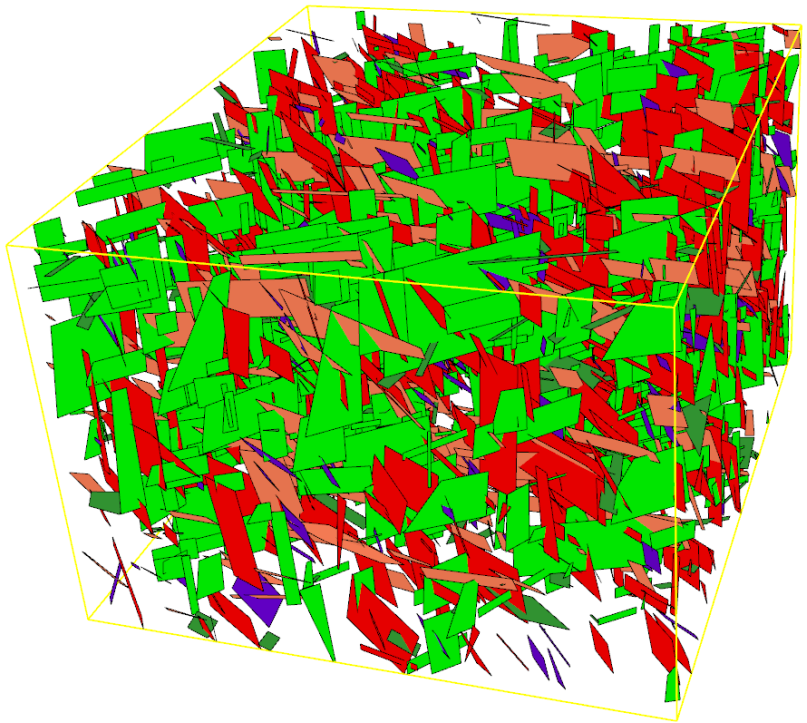
For the (ewG) **integrity analysis** thermal, hydraulic and mechanical (THM) processes, as well as their coupling, have to be considered in order to check if a significant change in the retention properties of the geological barrier occurs.




Multiple „ewG“
Generic geological model (Mrugalla et al. 2021), fractured crystalline rock, parameterization, heat source, initial and boundary conditions
Numerical analysis
DFN and FE continuum model
THM system behavior
Varying in space and time: Temperature, Pore pressure, Deformation, Stress tensor
Barrier integrity criteria (acc. to BMU 2020)
Temperature (T)
$\frac{T}{T_{Limit}} < 1$
Fluid pressure (H)
$p - \sigma_{\min} < 0$
Dilatancy (M)
$\frac{f(\boldsymbol{\sigma})}{f_{\mathrm{Limit}}(\boldsymbol{\sigma})} < 1$
Barrier integrity assessment

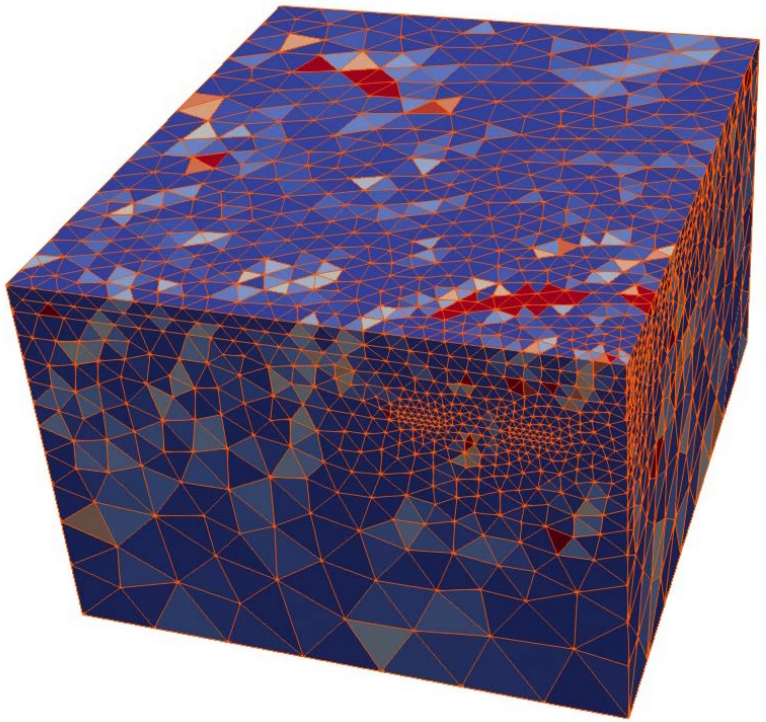
Model concept

Discrete fracture network (DFN)



- Discrete fractures (one realization)
- Process: Hydraulic (H)
- Software: Fracman® (www.golder.com/fracman)

Continuum model

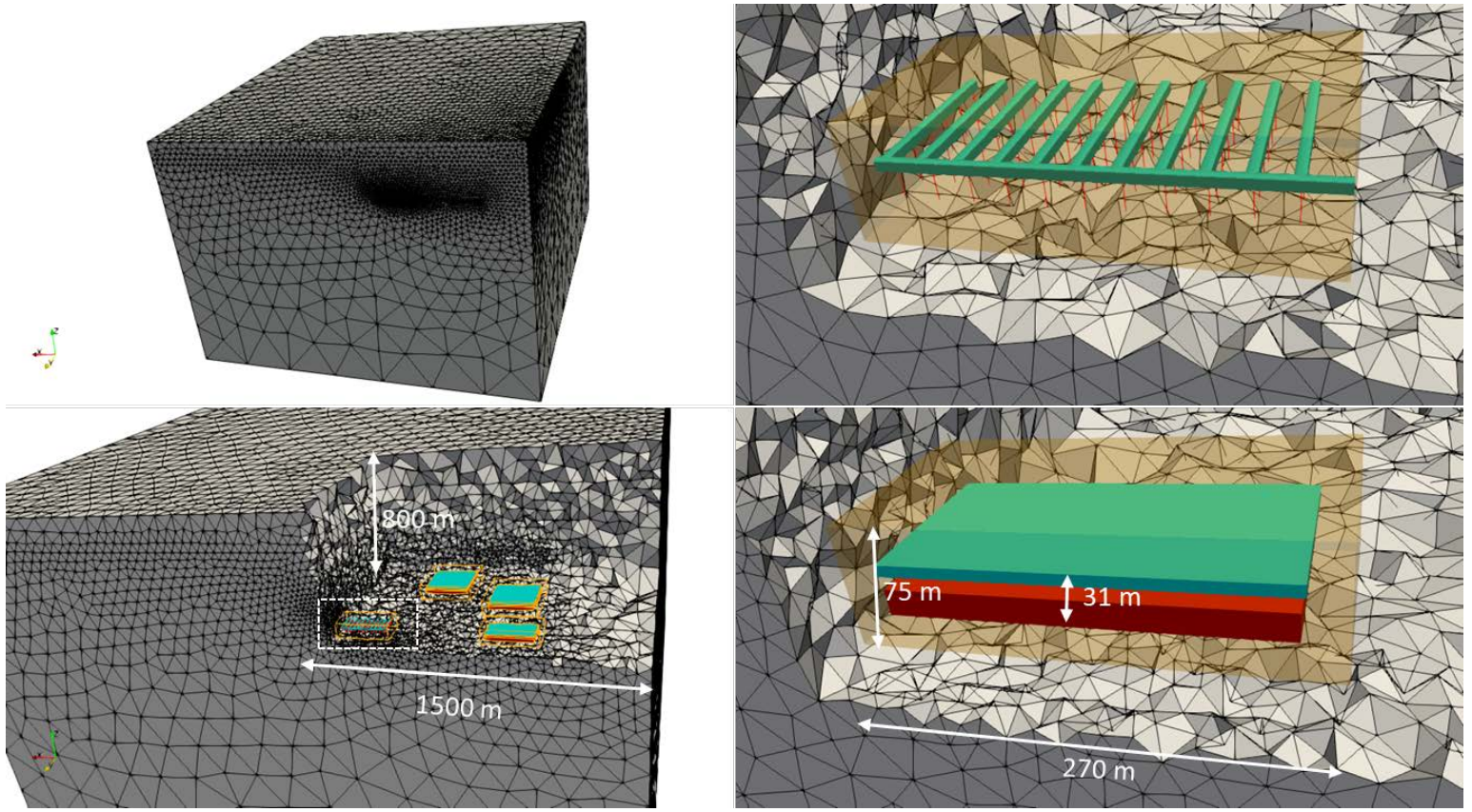


- Finite element (FE)
- Processes: (coupled) THM
- Upscaled fractured properties from DFN
- Software: OpenGeoSys (OGS) version 5 (Kolditz et al., 2012a)

FE model mesh

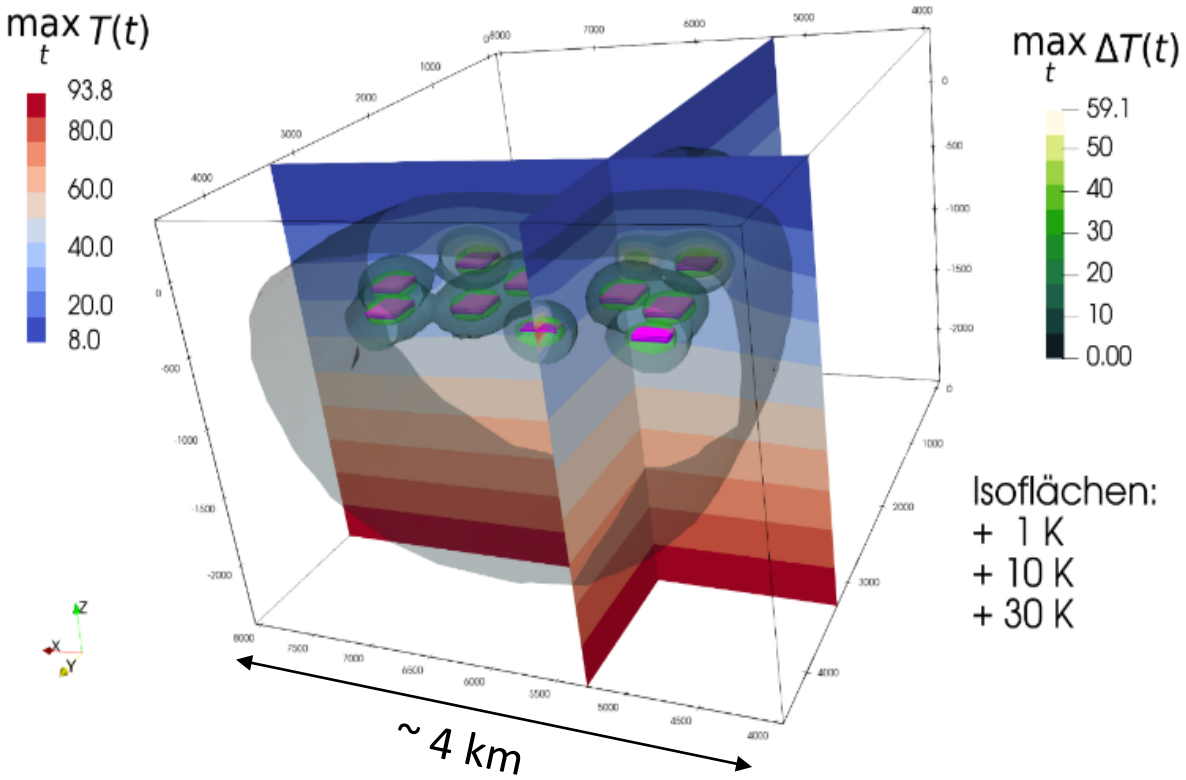
3D Continuums model

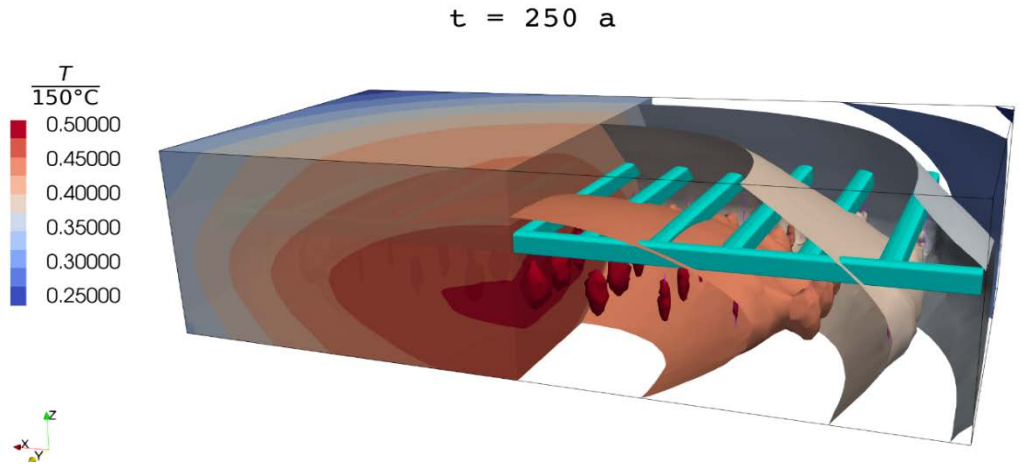
- Finite element mesh
- Tetrahedral elements
- Fractures are not considered here
- Finer discretization in the ewG regions (Element edge length about 0,3 m)
- Coarser elements at the bottom edge of the model (edge length up to about 700 m)
- Model domain is discretized with 573,942 tetrahedron elements and 92,553 nodes

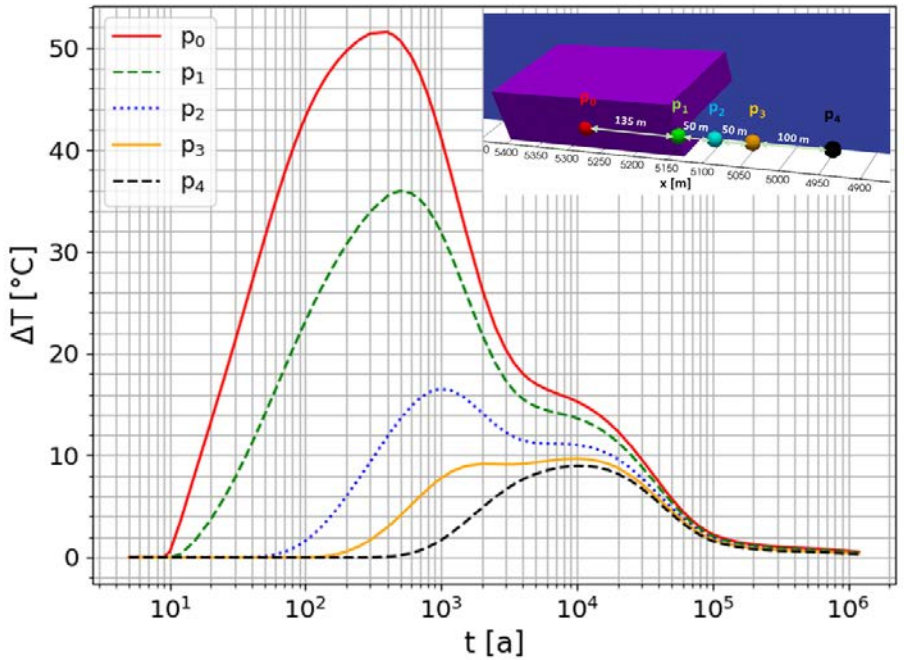


Temperature

- Geothermal gradient
- Temperature increase due to heat of decay
- Maximum temperature decreases with distance
- Temperature criteria is fullfilled

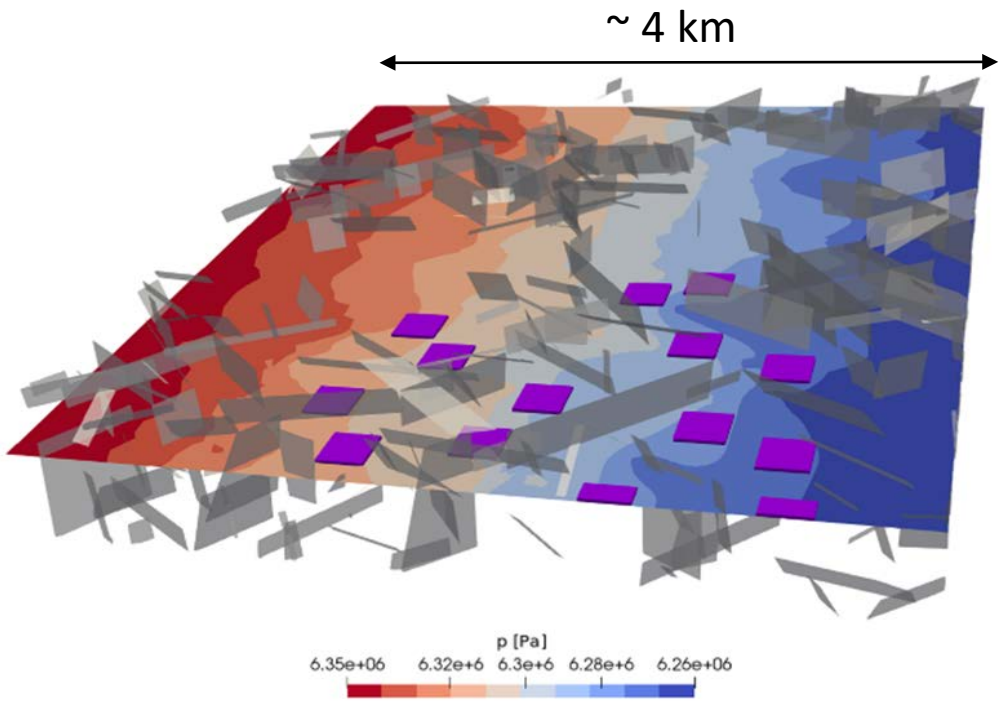




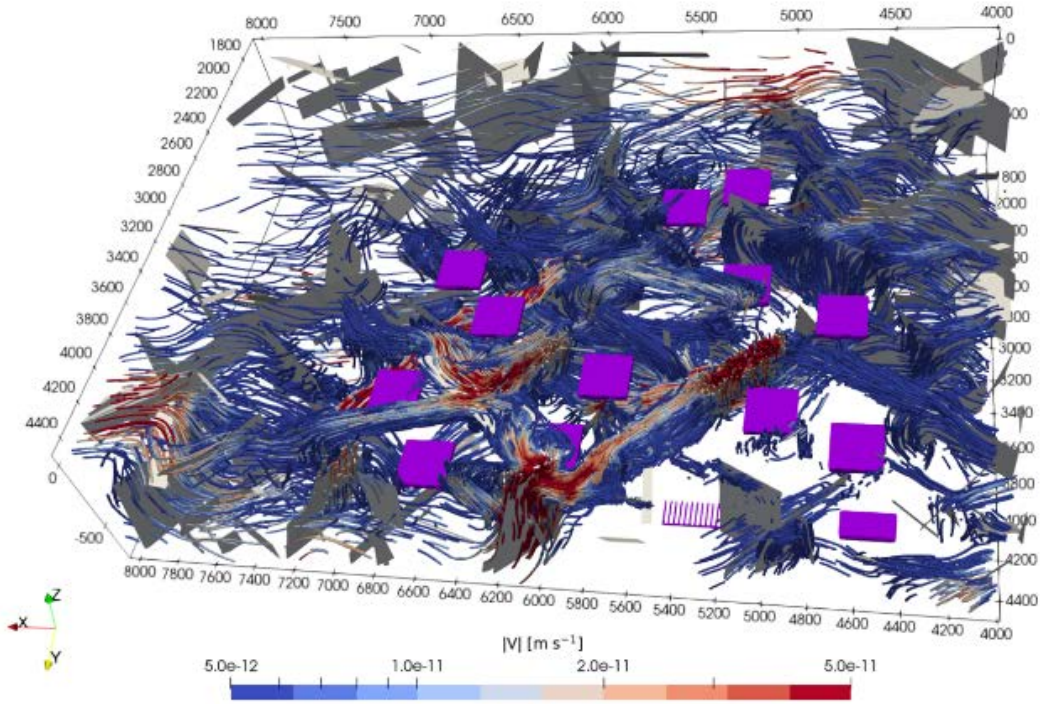


Hydraulic

- Regional horizontal gradient
- Heterogeneous and anisotropic permeability
- Obtained through upscaled DFN properties

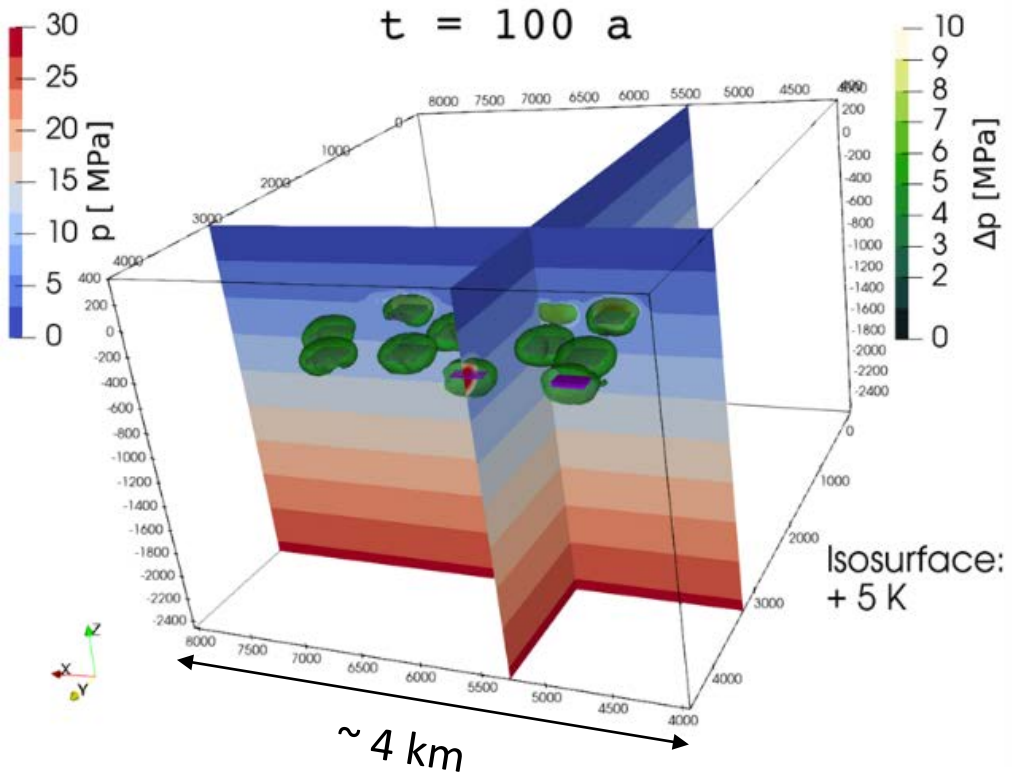


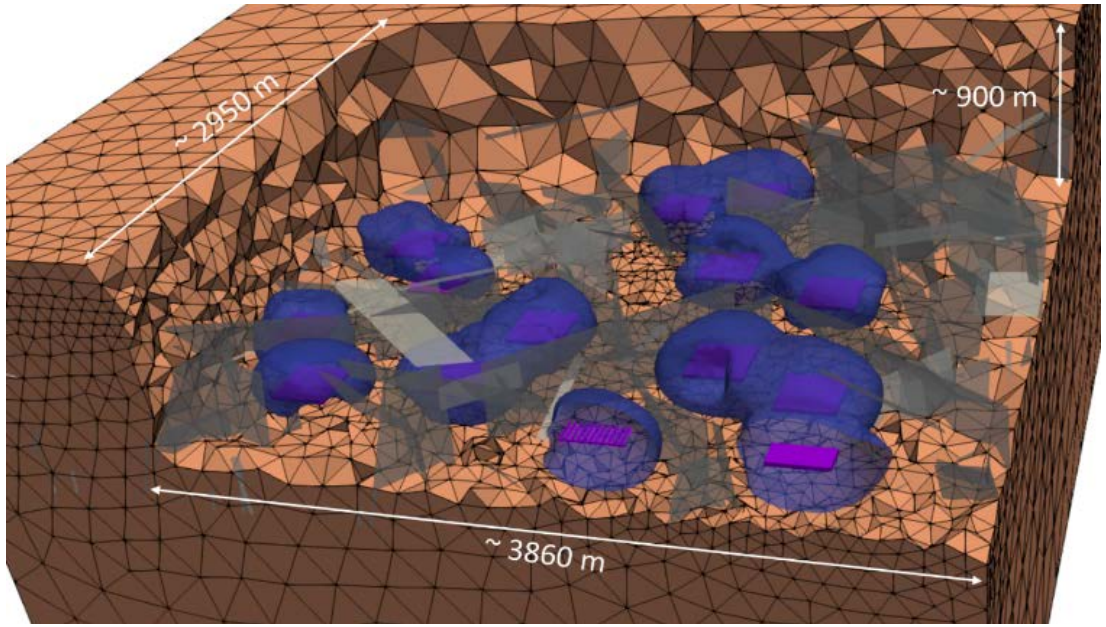
- Stationary flow at ewG Plane (~204 m)
- Flow regime is fracture dominated
- $V_{Fractures}/V_{Matrix}$ ~ 1e5

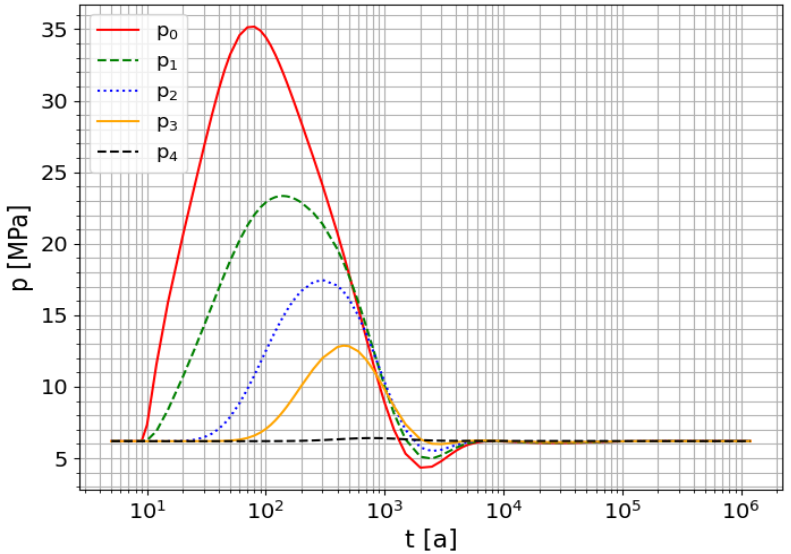


Hydraulic

- Pore fluid pressure (p) increase due to temperature rise
- Fractures influence on p behavior

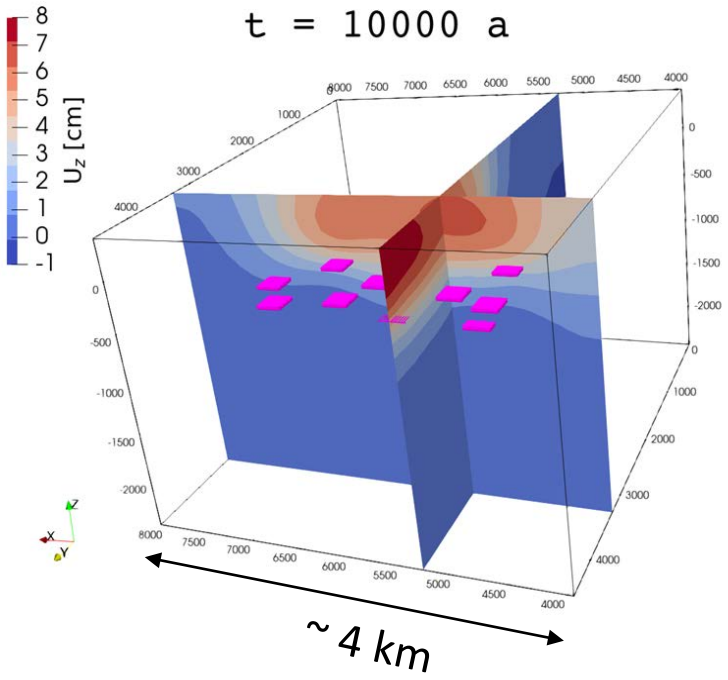




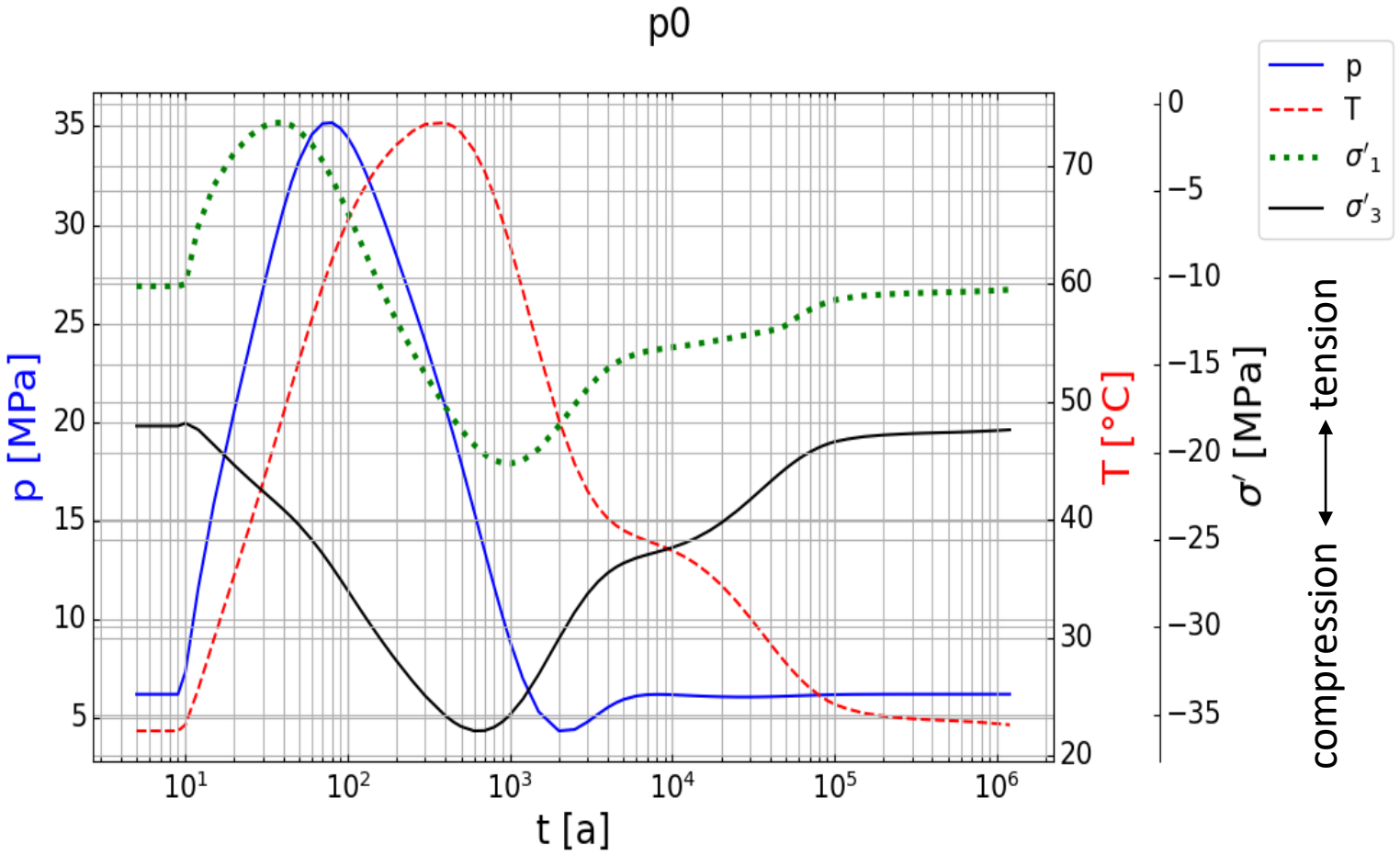


Mechanic

- Non-isothermal linear poroelasticity
- Uplift due to thermal expansion



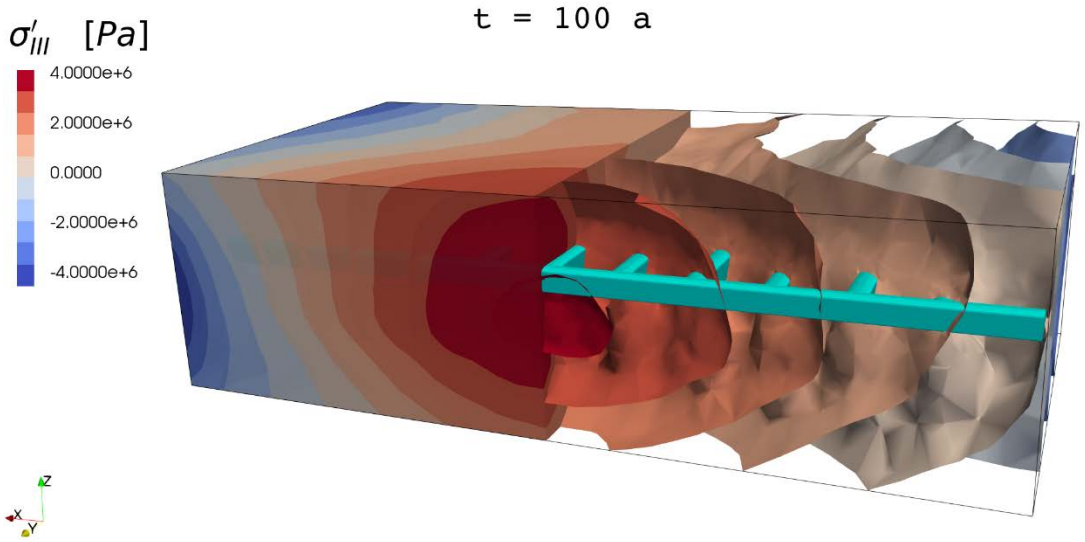
- Temperature (T) follows heat source
- Pore fluid expands with increasing temperature
- Pore fluid pressure (p) increase
- Compressive stress decrease due to p increase (max σ'_1)
- Compressive stress increase due to thermal solid expansion (min σ'_3)



Integrity criteria

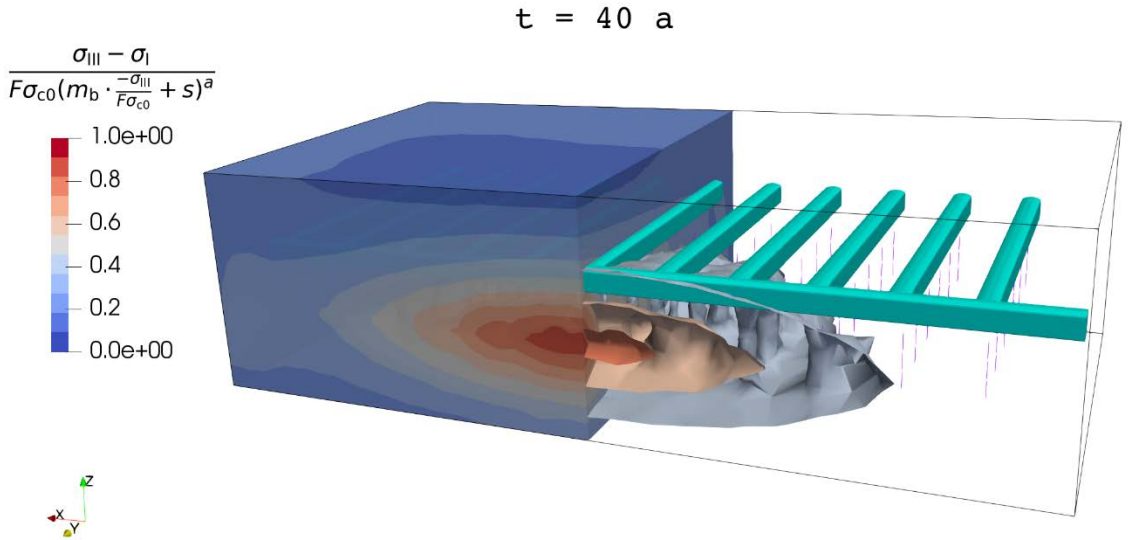
- **Fluid pressure criteria**
  - No tensional effective stress occur
  - Fluid pressure is considered due to THM (Biot) coupling
  - Criteria is fullfilled when:

$$\sigma'_{III} = \sigma^{tot}_{III} + \alpha p < 0$$



- **Dilatancy criteria**
  - Evaluation using Hoek-Brown criteria
  - Criteria is fullfilled when:

$$\frac{\sigma'_{III} - \sigma'_{I}}{F \cdot \sigma_{c0}(m_b \cdot \frac{-\sigma'_{III}}{F \cdot \sigma_{c0}} + s)^a} < 1$$



Summary

- A modeling concept for integrity assessment and improvement of system understanding for the repository system "multiple ewG" was proposed and successfully applied
- It was shown that the proposed modeling concept can be applied for fractured systems and leads to plausible results.
- Fracture dominant system
- Strong coupled THM system

Outlook

- Consideration of near-field processes
- Upscaling of mechanical properties (e.g. E Module)
- Quantification of uncertainties