Supplement of Saf. Nucl. Waste Disposal, 1, 165–167, 2021
https://doi.org/10.5194/sand-1-165-2021-supplement

Supplement of

Building the bridge between safety requirements and numerical modeling: an example considering crack development of Opalinus clay in laboratory and field scales

Tuanny Cajuhi et al.

Correspondence to: Tuanny Cajuhi (tuanny.cajuhi@bgr.de)

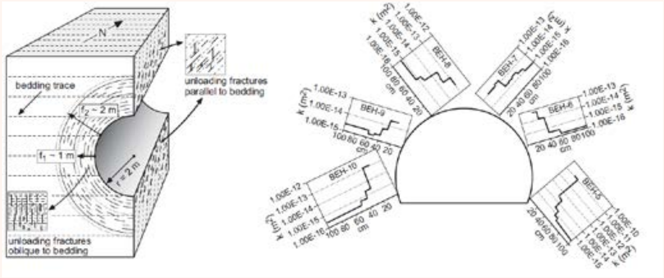
Building the bridge between safety requirements and numerical modeling: An example considering crack development of Opalinus Clay in laboratory and field scales

Tuanny Cajuhi, Jobst Maßmann and Gesa Ziefle

Bundesanstalt für Geowissenschaften und Rohstoffe (BGR)

Motivation & Aims

- Motivation
  - Radioactive waste needs to be stored in a safe and sustainable manner
  - The integrity of the rock, i.e. its containment capabilities, must be ensured
  - Understanding the coupled phenomena taking place in the rock needs, ideally, to occur at the in-situ scale

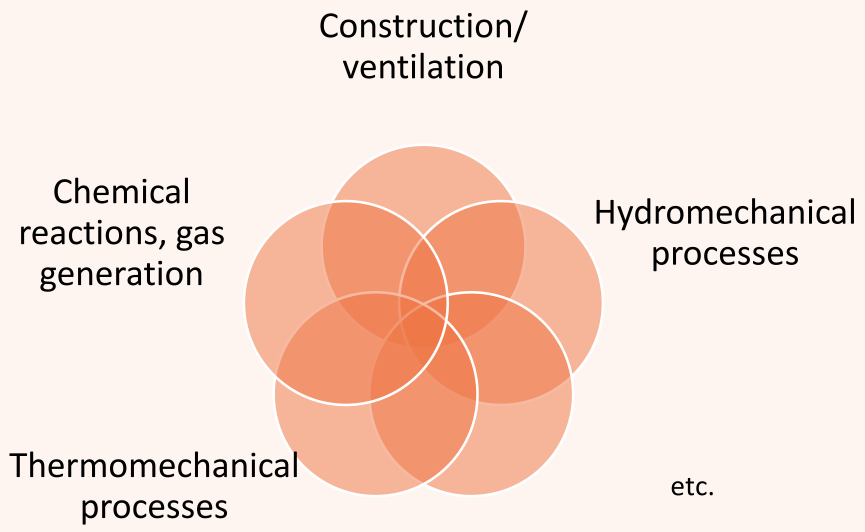


Conceptual model extracted from [Tsang et al. 2012]

- Aims
  - Correlate process understanding in the near field and its impact on the integrity of the containment providing rock zone (CRZ)
  - Illustrate an example for the role of numerical modeling in safety assessment

Scope

- “The term integrity describes the conservation of the properties related to the confining capacity of the containment providing rock zone of a repository”
  „Der Begriff Integrität beschreibt den Erhalt der Eigenschaften des Einschlussvermögens des einschlusswirksamen Gebirgsbereichs eines Endlagers“ [BMU 2020]
- What can affect the integrity? For how long?
- Which processes are correlated to a possible integrity loss?

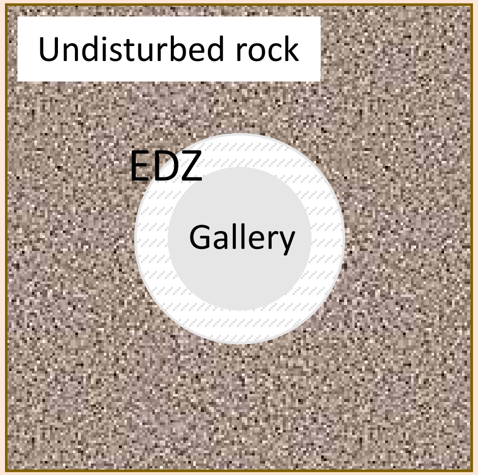


In the field

Bundesanstalt für Geowissenschaften und Rohstoffe
GEOZENTRUM HANNOVER

safe ND
Interdisziplinäres Forschungssymposium für die Sicherheit der nuklearen Entsorgung

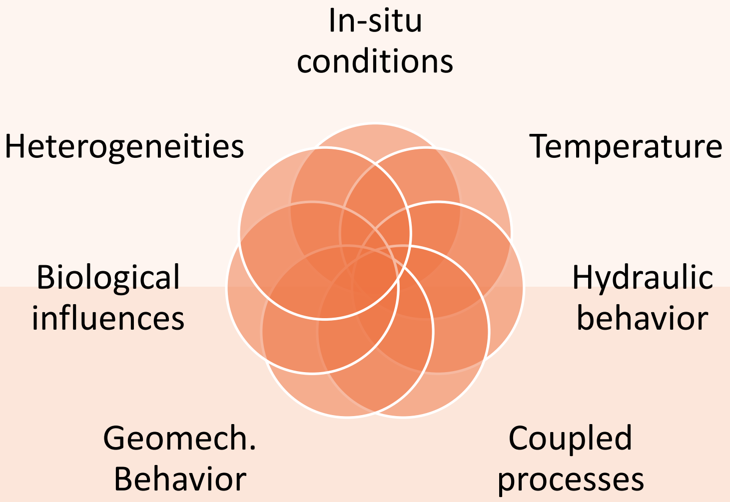
- Initial condition
- Excavation
  - Stress redistribution
  - Plastic behavior (shear / compressive strength criterion)
  - EDZ development (cracks, permeability increase)
- Functional period
  - Wetting and drying (seasonal changes)
  - Further degradation and/or increase of EDZ
    - Cracks due to drying

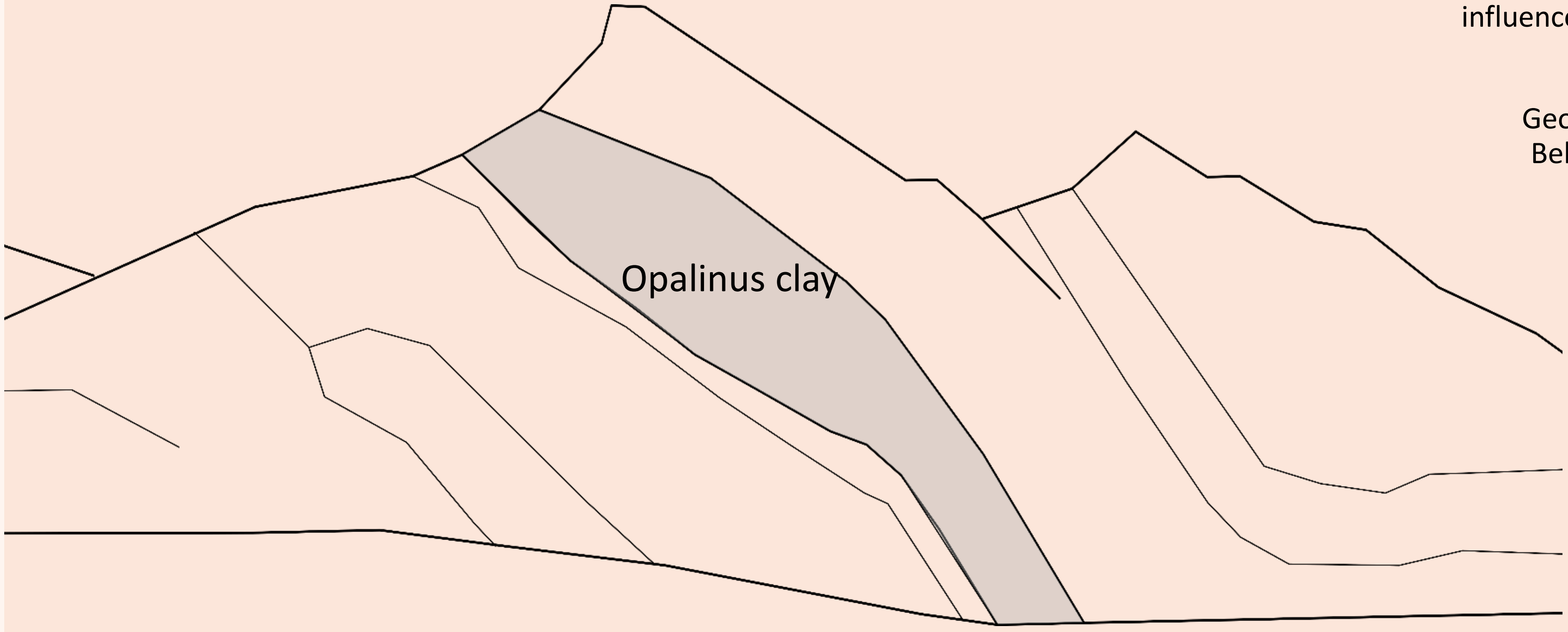


OPA [Technischer Bericht 14-02 Nagra]

Practical steps
Formulation

- The “host” rock
- Mont Terri Rock Laboratory





Goal statement

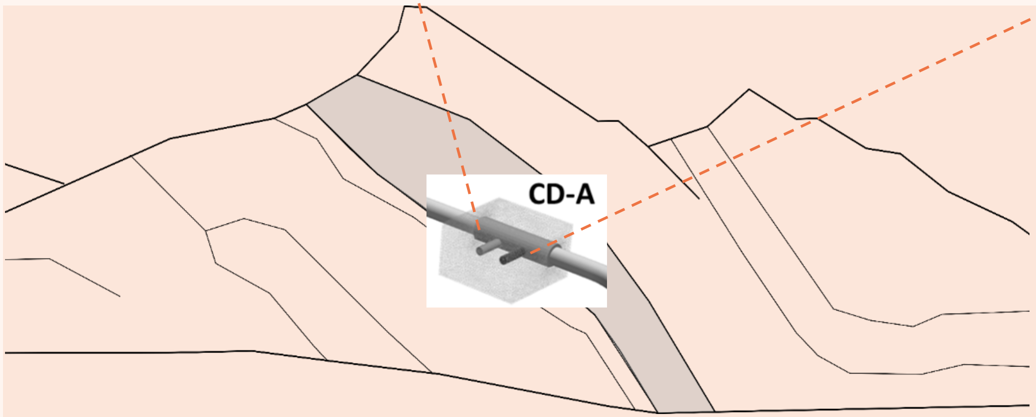
What are the points we would like to tackle?

Practical steps
Simplification

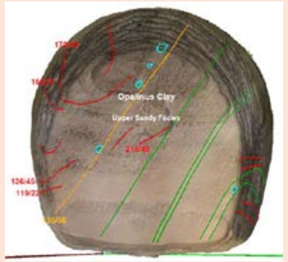
- Cyclic-Deformation (CD-A) experiment: *free* twin niches

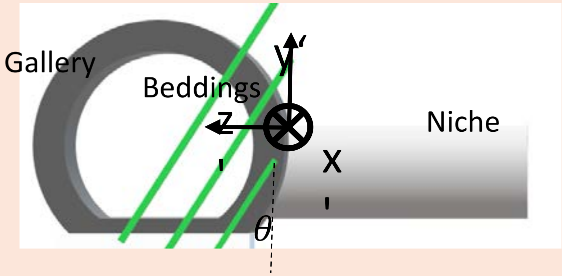
Open niche
- Seasonal humidity variations

Closed niche
- Controlled high humidity



Simplifications





Practical steps
Mathematical modeling

Bundesanstalt für Geowissenschaften und Rohstoffe
GEOZENTRUM HANNOVER

safeND Interdisziplinäres Forschungssymposium für die Sicherheit der nuklearen Entsorgung

- Hydro-mechanical (HM) framework
  - Balance equations

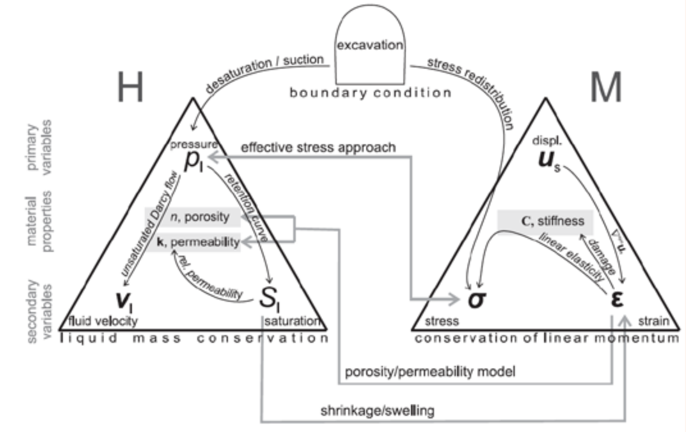
$$\nabla \cdot (n S_l \mathbf{v}_{ls}) + \rho_l \left[C_s \frac{\partial p_l}{\partial t} + S_l \alpha \frac{\partial \mathrm{tr}(\nabla^s \mathbf{u})}{\partial t} \right] = 0$$

$$\nabla \cdot (\boldsymbol{\sigma}' - \alpha S_l p_l \mathbf{I}) + n S_l \rho_l \mathbf{g} + (1 - n)\rho_s \mathbf{g} = \mathbf{0}$$

- Constitutive relations
  - Transversely isotropic, linear elastic material
  - Van Genuchten fitting

- Initial conditions

$$p_w = p_{w_0} \text{ at } t = 0$$
$$\mathbf{u} = \mathbf{u}_0 \text{ at } t = 0$$
$$\sigma_0 \text{ at } t = 0$$



[Maßmann 2009]

- Capillary pressure (**Richards** assumption)

$$p_c = p_g - p_l$$
$$p_g = p_{atm}$$

- Rate of liquid flow (Darcy‘s law)

$$n S_l \mathbf{v}_{ls} = -\rho_l k_{rl} \frac{\mathbf{K_i}}{\mu_l} (\nabla p_l - \rho_l \mathbf{g})$$

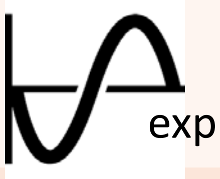
- Boundary conditions

$$\mathbf{u} = \bar{\mathbf{u}} \text{ on } \Gamma_u$$
$$\boldsymbol{\sigma} \cdot \mathbf{n} = \bar{\mathbf{t}} \text{ on } \Gamma_t$$
$$p_w = \bar{p}_l \text{ on } \Gamma_p$$
$$\bar{q} \text{ on } \Gamma_q$$

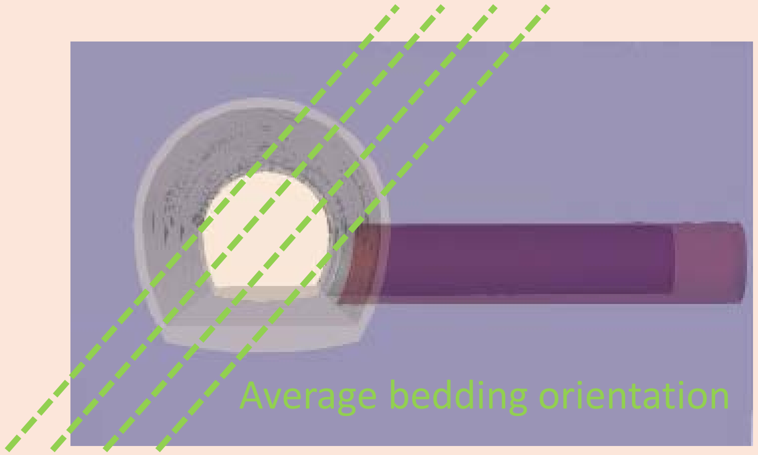
OpenGeoSys
OPEN-SOURCE MULTI-PHYSICS

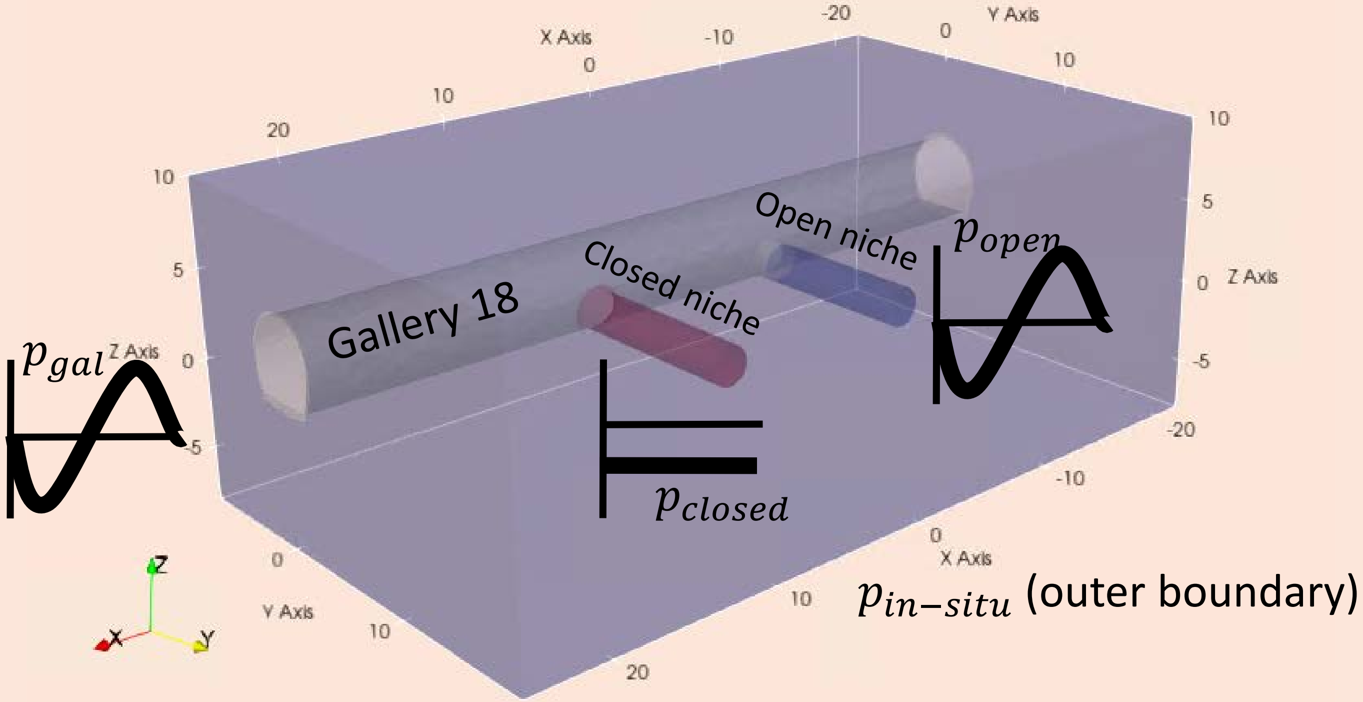
Practical steps
Numerical modeling

- Design
- First predictions using independent (in-/output) data from the experiment



IC
$\sigma_{in-situ}$
$p_{in-situ}$





Practical steps
Numerical modeling

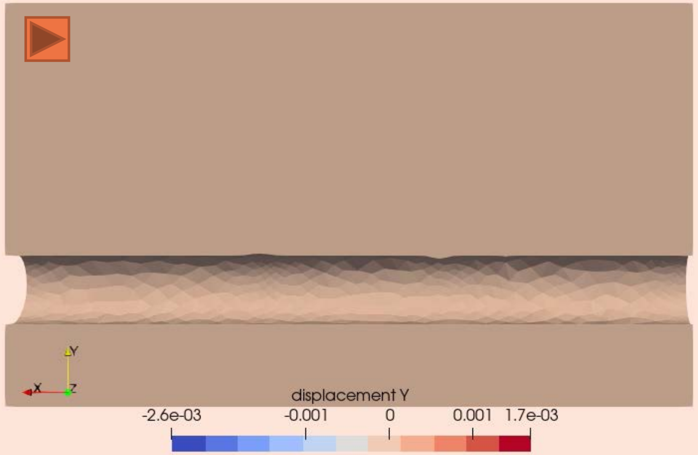
Bundesanstalt für Geowissenschaften und Rohstoffe
GEOZENTRUM HANNOVER

safe ND
Interdisziplinäres Forschungssymposium für die Sicherheit der nuklearen Entsorgung

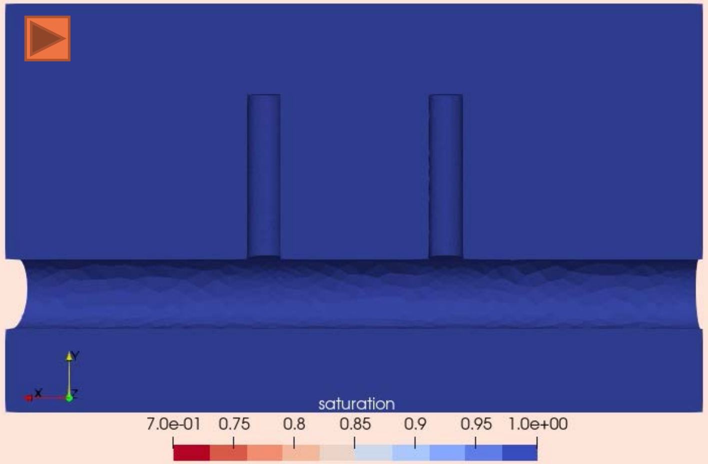
- Initial conditions and influence of excavation
- Hydro-mechanical behavior (long-term)
- Comparison with experiments within interdisciplinary approach Ziefle et al. 2021 (under review)

- Integrity?
- How far is the near field?

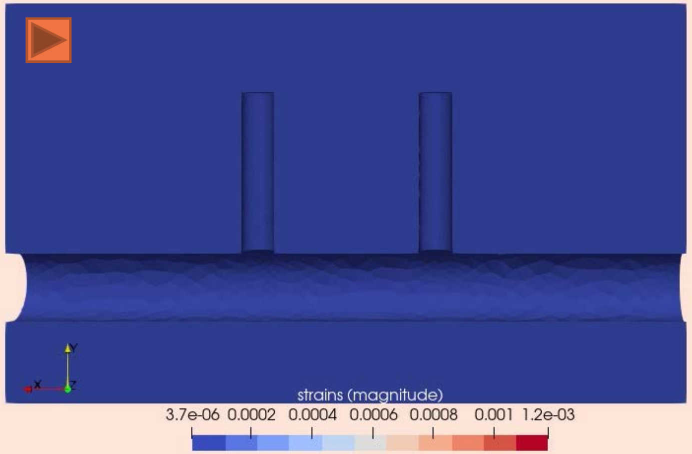
Extension



Displacement during excavation (HM)



Saturation (HM)

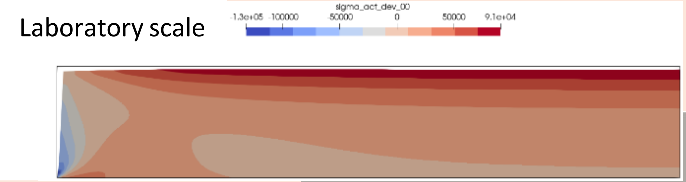


Strains (HM)

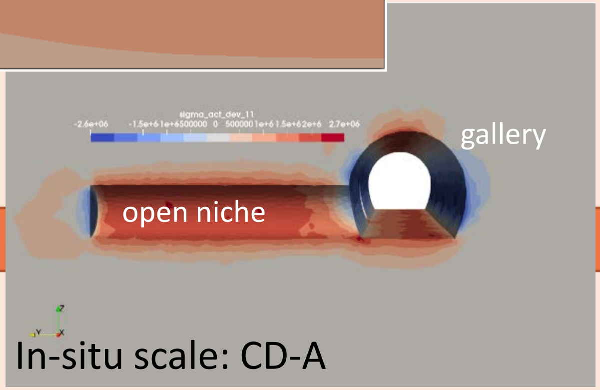
Practical steps
Model extension

BGR Bundesanstalt für Geowissenschaften und Rohstoffe
GEOZENTRUM HANNOVER
safeND Interdisziplinäres Forschungssymposium für die Sicherheit der nuklearen Entsorgung

- Identification of the mechanisms at the field and laboratory scales: shrinkage-swelling, cracking
- Application of the method in the smaller scale: assessment of numerical problems
- Adaptation and verification at larger scale



Stress distribution

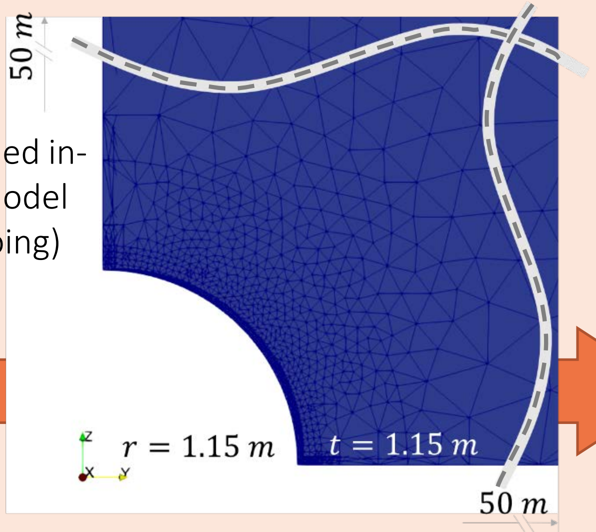


GEOMINT

Cooperation
K. Yoshioka (UFZ)
T. Nagel (TUBAF)

Desiccation cracks

Simplified in-situ model (ongoing)



Extension of HM model with phase-field framework to account for crack evolution

Conclusions & Outlook

- Correlate process understanding and integrity requirements
- Practical steps on numerical modeling
  - CD-A experiment, Mont Terri
  - Use of experimental data
  - Simulation of excavation and long-term behavior
- Further development and application of numerical methods
  - Identification of mechanisms at laboratory and field scales
  - Concept and perspectives for modeling cracking
  - Transfer between the scales