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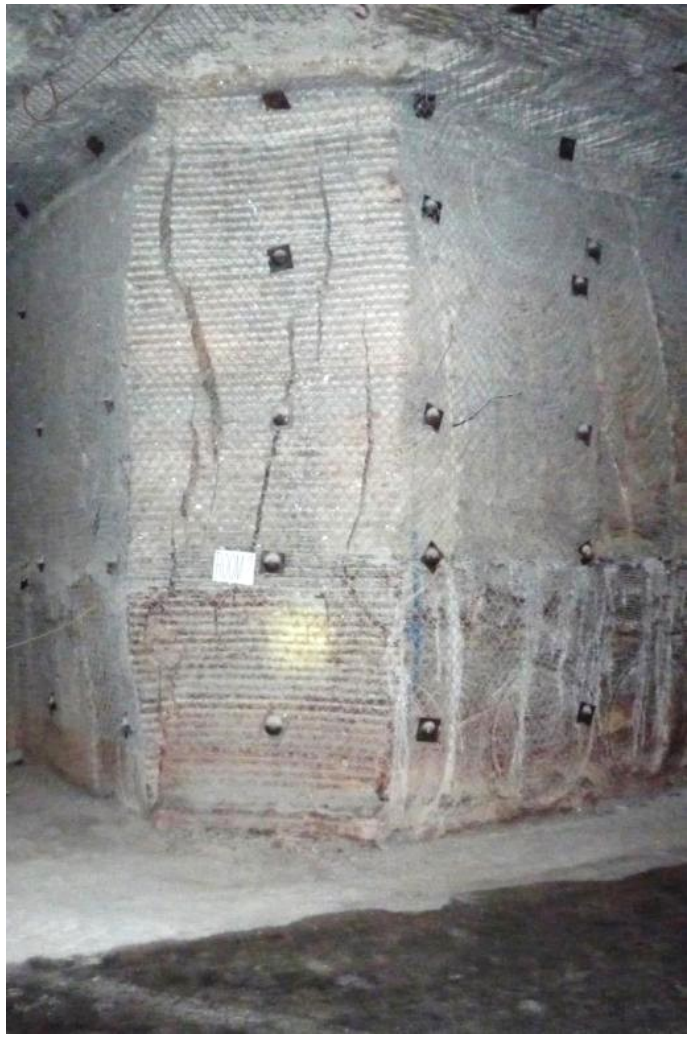
Technische Universität Braunschweig

Anisotropic permeability in the EDZ of drifts in rock salt
A numerical approach

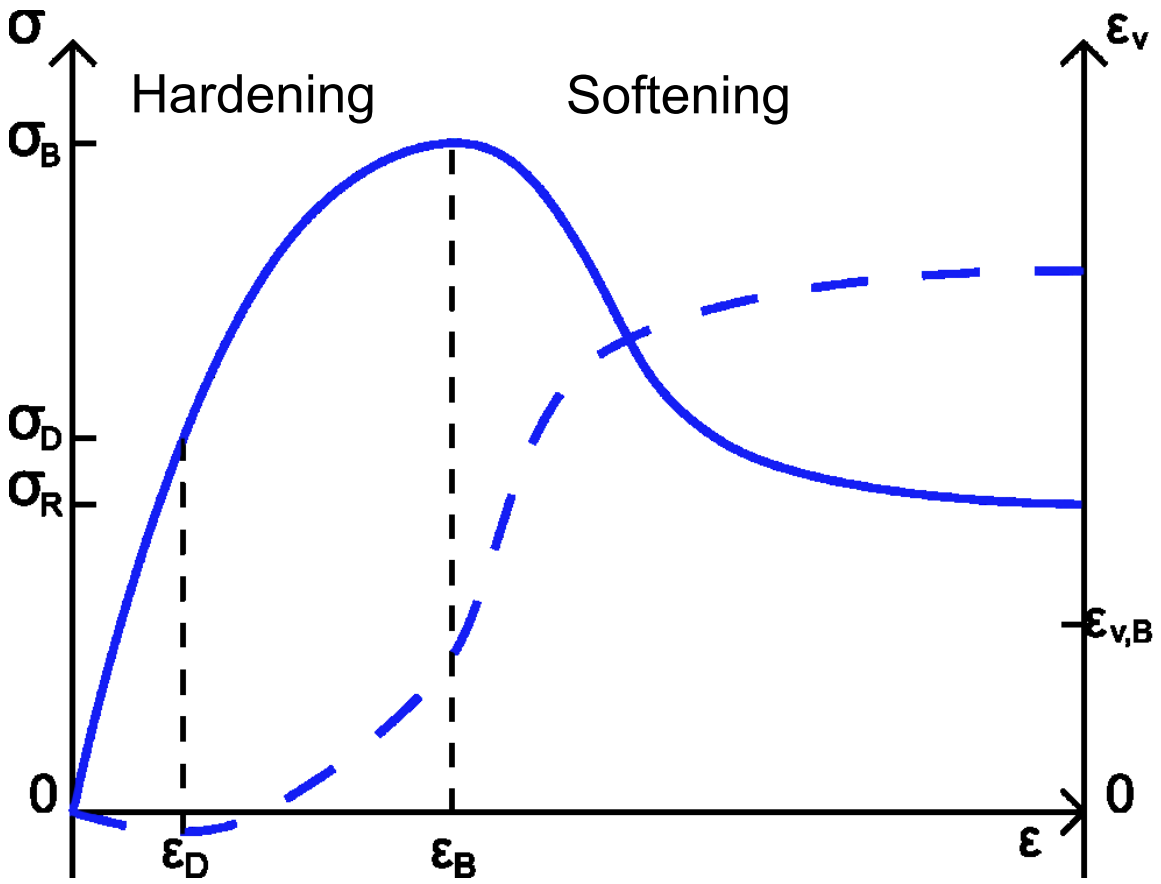
Christian Missal & Joachim Stahlmann

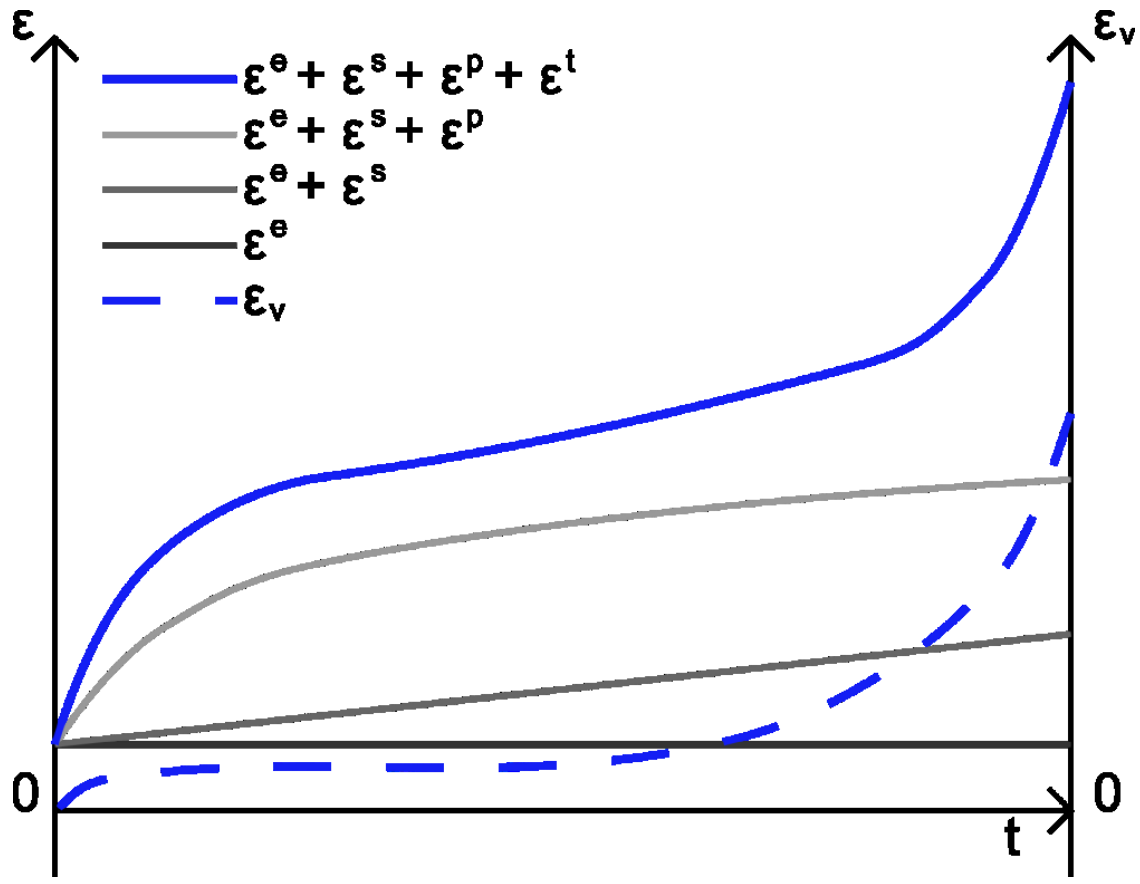
5th International Itasca Symposium – Vienna, 2020

Rock salt



Rock salt – Mechanical behavior

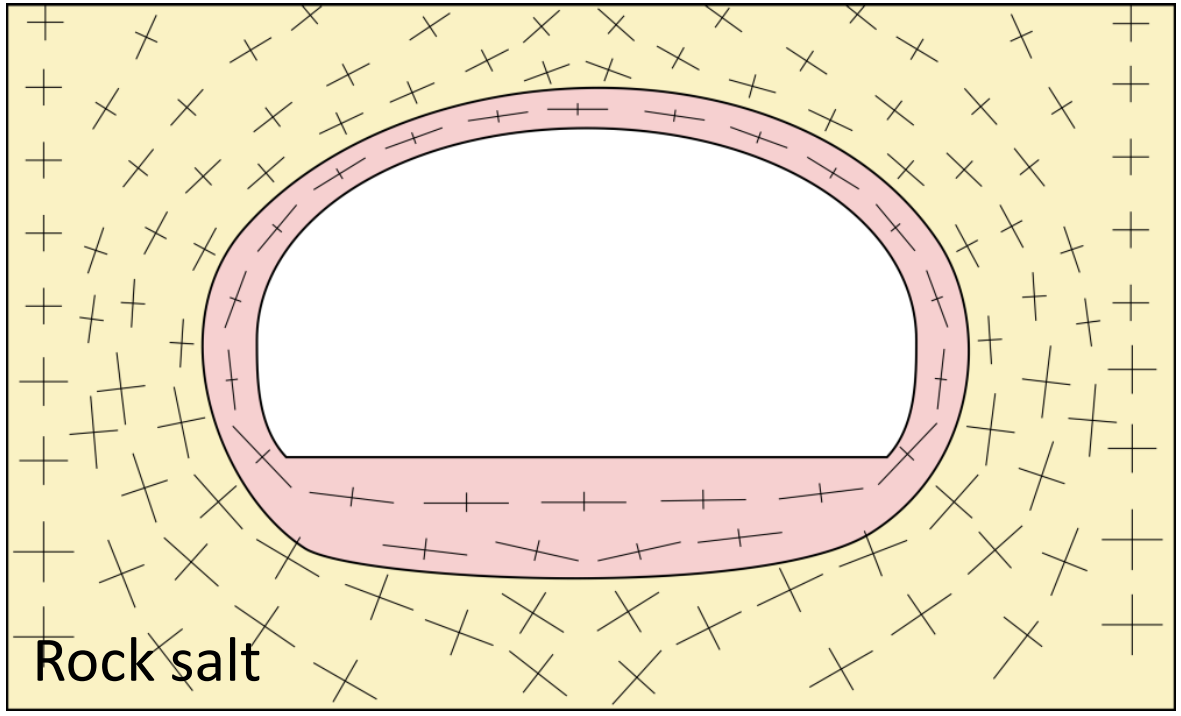




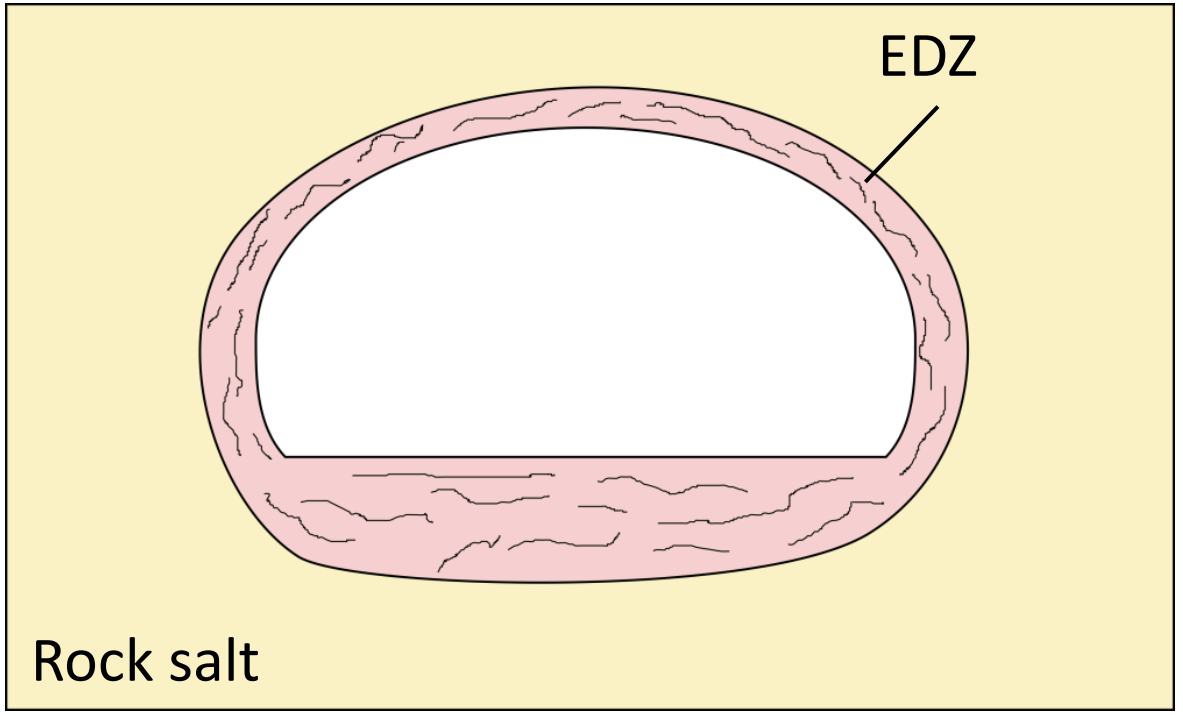
[Missal et al., 2016a]

Rock salt – Excavation damge zone (EDZ)

Stress state

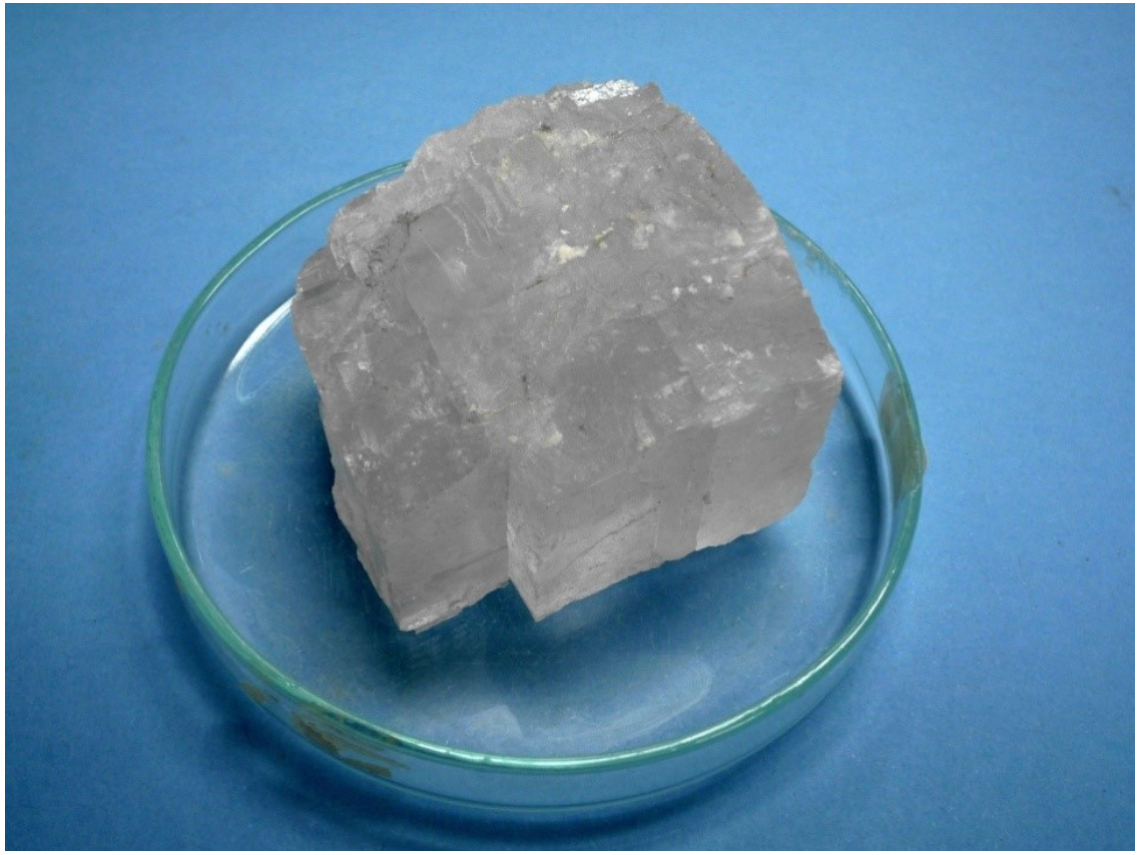


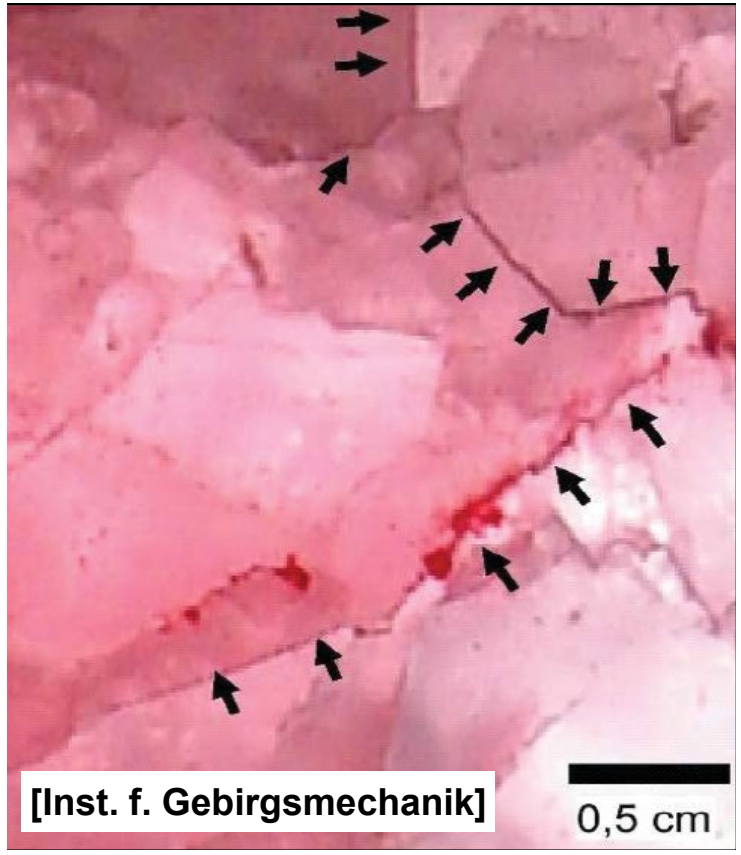
Damage in the EDZ



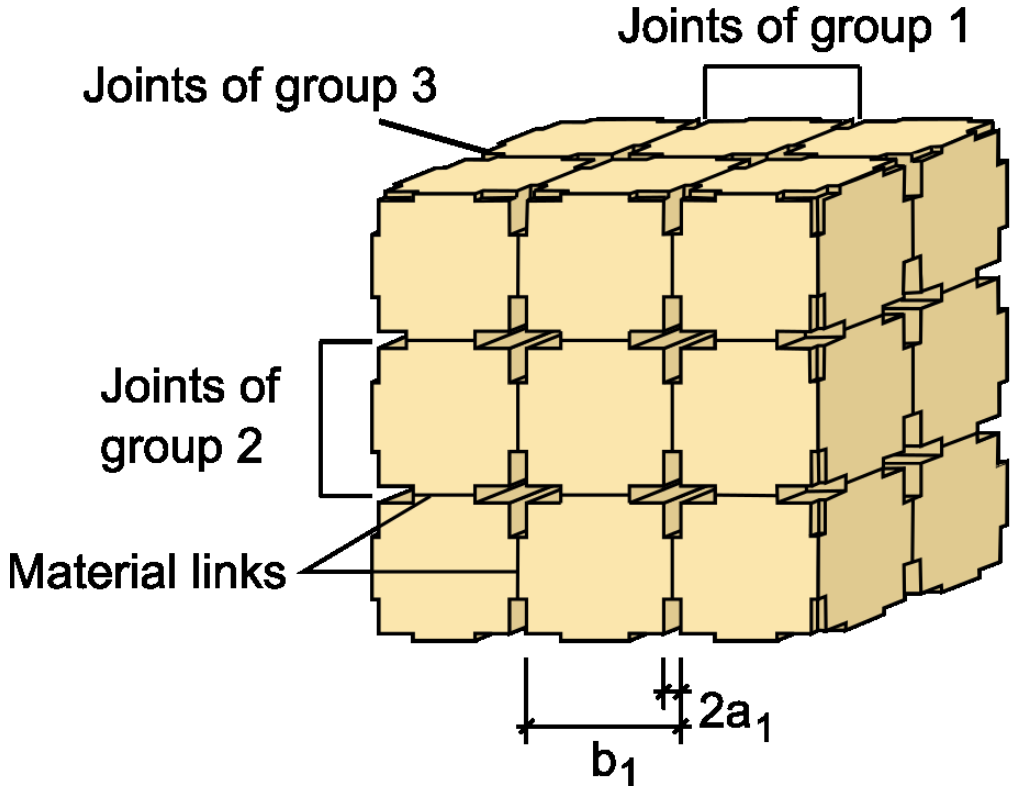
[Missal, 2019]

Paths of fluid flow in salt mechanic





Paths of fluid flow in rock mechanic

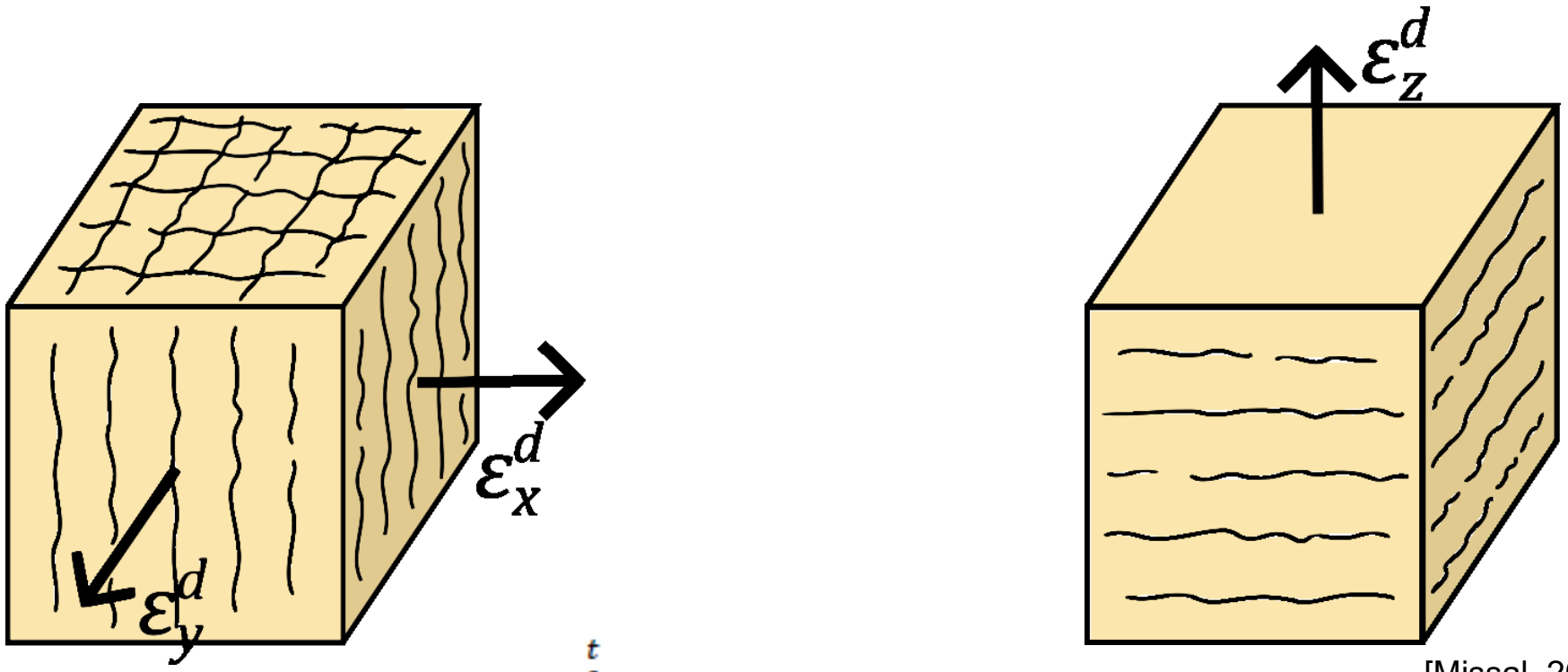


[Rodatz, 1973]

Orientation of cracks and resulting permeability

Compression

Extension

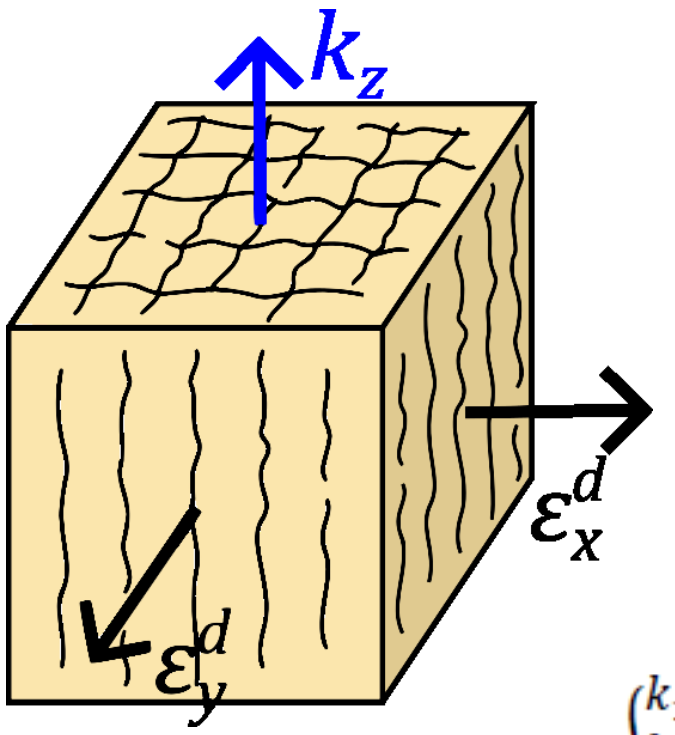


[Missal, 2019]

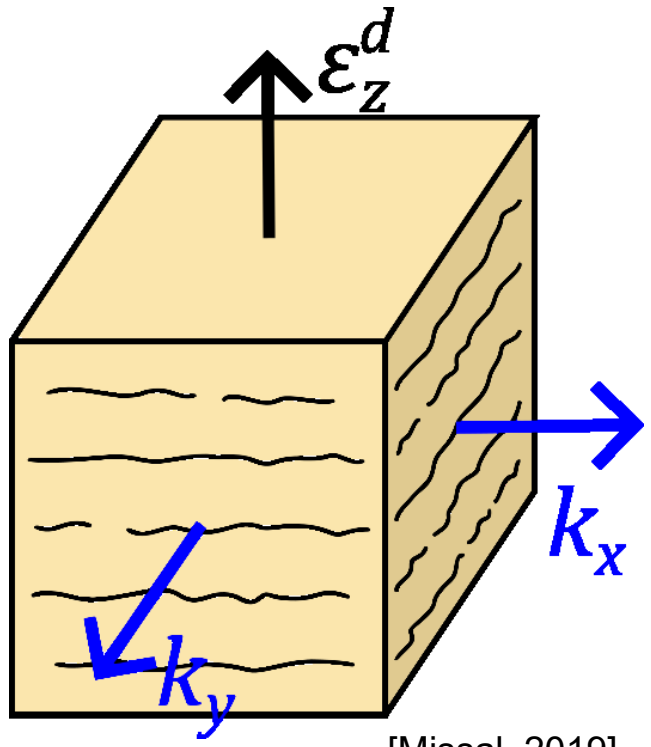
$$\{\varepsilon^d\} = \int_{t=0}^{t} (\{\dot{\varepsilon}^t\} \cdot \mathrm{d}t + \{\dot{\varepsilon}^v\} \cdot \mathrm{d}t + \{\varepsilon^z\})\mathrm{d}t$$

Orientation of cracks and resulting permeability

Compression



Extension



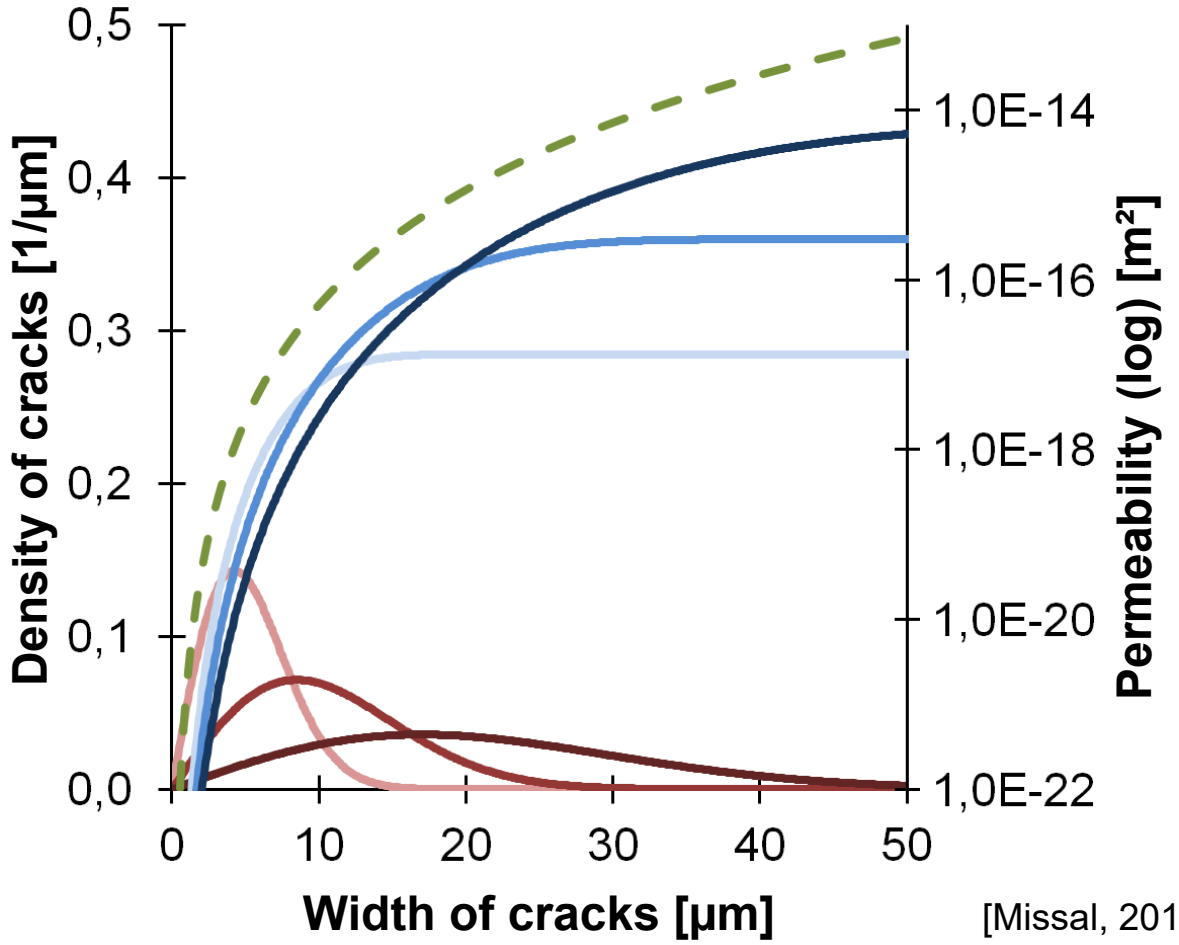
$$\begin{Bmatrix} k_1 \\ k_2 \\ k_3 \end{Bmatrix} = \begin{Bmatrix} f(\varepsilon_2^d) + f(\varepsilon_3^d) \\ f(\varepsilon_3^d) + f(\varepsilon_1^d) \\ f(\varepsilon_1^d) + f(\varepsilon_2^d) \end{Bmatrix}$$

[Missal, 2019]

Influencing factors on the permeabilty

Crack spectrum
- Damage-induced strains
- Stress state

Crack permeability
- Crack spacing
- Crack roughness



[Missal, 2019]

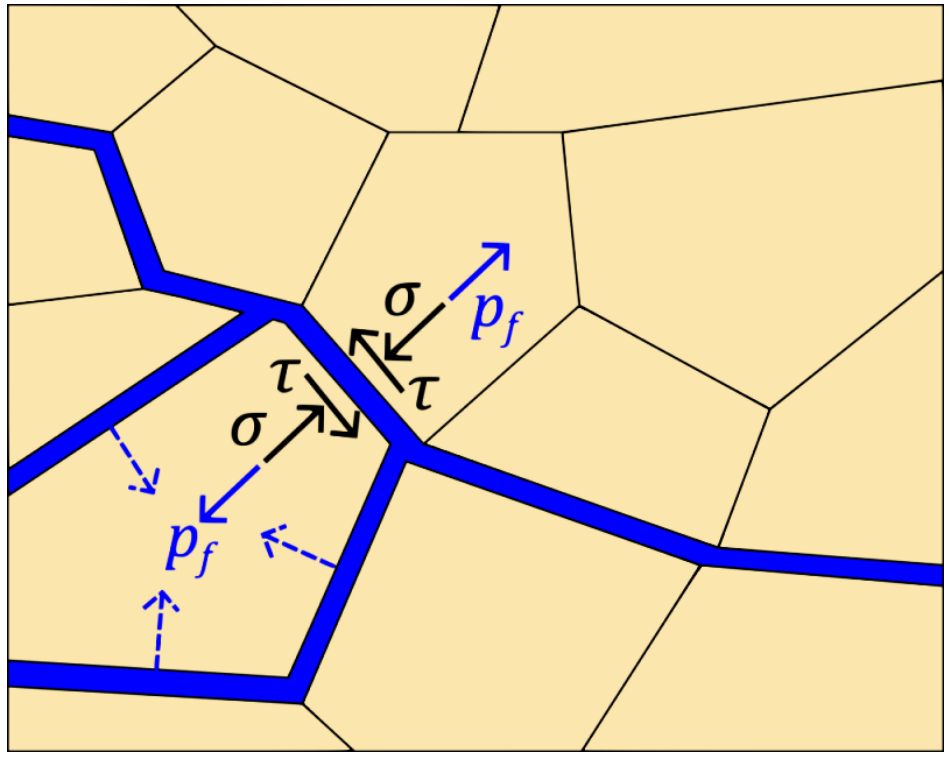
Influencing factors on the permeabilty

Crack spectrum
- Damage-induced strains
- Stress state

Crack permeability
- Crack spacing
- Crack roughness

Crack cross-linking

Fluid pressure / normal stress
→ $\Delta 2x_N$



[Missal, 2019]

Functional relationship

Crack cross-linking

$$\{P(\varepsilon_v^d, \varepsilon_i^d)\} = \left\{\left\langle \frac{\varepsilon_v^d \cdot (1 + p_1 \cdot \varepsilon_i^d)}{\varepsilon_{v,B}^d} - p_c \right\rangle\right\}$$

Crack permeability

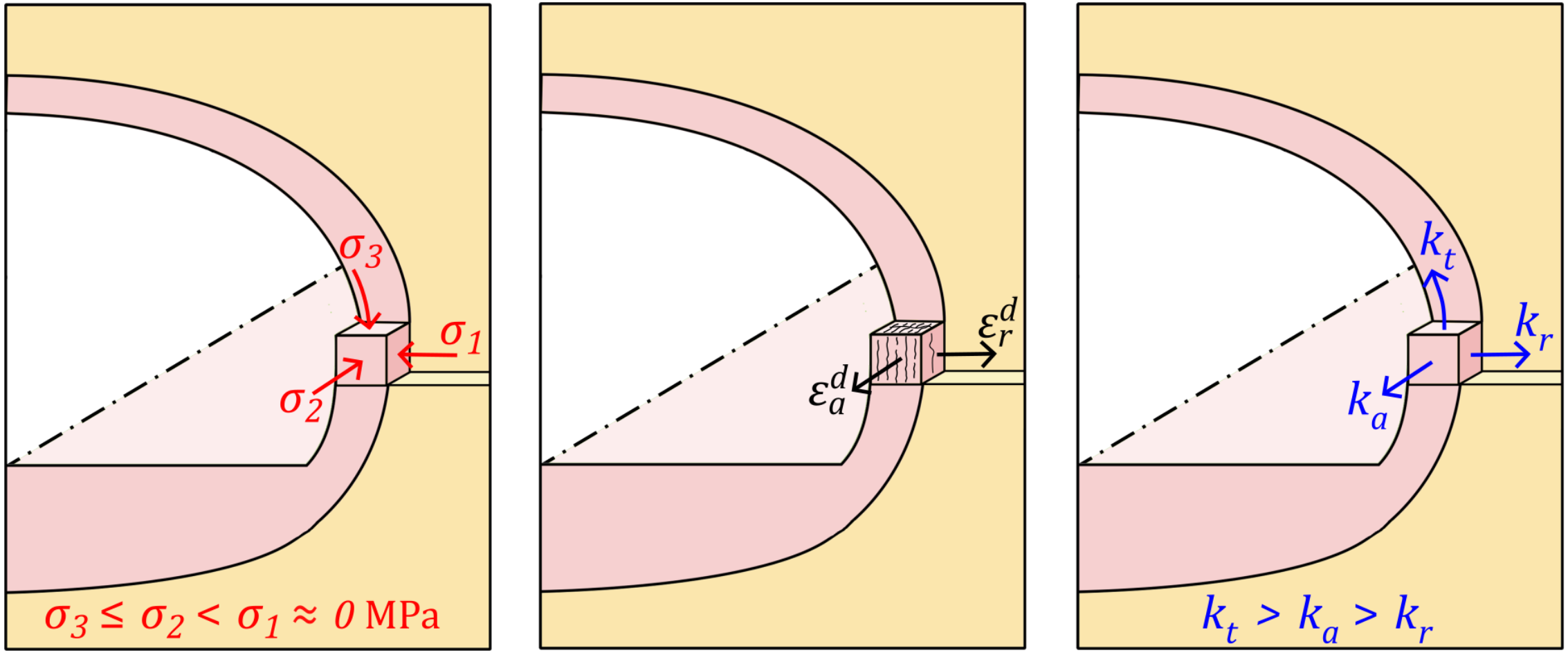
$$k^*(x) = \frac{\langle 2x + \Delta 2x_N \rangle^3}{12 \cdot \overline{b}_K \cdot \left(1 + 8{,}8 \cdot H\left(\frac{\overline{d}_r}{d_H^*} - 0{,}032\right) \cdot \left(\frac{\overline{d}_r}{d_H^*}\right)^{\frac{3}{2}}\right)}$$

Crack spectrum

$$D(x^*, \underline{\sigma}) = \begin{cases} \frac{x^*}{\underline{\sigma}^2} e^{-\frac{x^{*2}}{2\underline{\sigma}^2}} & \text{für } x > 0 \wedge \underline{\sigma} > 0 \\ 0 & \text{für } x \leq 0 \vee \underline{\sigma} \leq 0 \end{cases}$$

$$\begin{Bmatrix} k_1 \\ k_2 \\ k_3 \end{Bmatrix} = k_{ini} + \begin{Bmatrix} \int_0^\infty \left(P(\varepsilon_v^d, \varepsilon_2^d) \cdot D\left(x^*, \underline{\sigma}(\varepsilon_2^d)\right) \cdot k^*(x) + P(\varepsilon_v^d, \varepsilon_3^d) \cdot D\left(x^*, \underline{\sigma}(\varepsilon_3^d)\right) \cdot k^*(x)\right) dx^* \\ \int_0^\infty \left(P(\varepsilon_v^d, \varepsilon_3^d) \cdot D\left(x^*, \underline{\sigma}(\varepsilon_3^d)\right) \cdot k^*(x) + P(\varepsilon_v^d, \varepsilon_1^d) \cdot D\left(x^*, \underline{\sigma}(\varepsilon_1^d)\right) \cdot k^*(x)\right) dx^* \\ \int_0^\infty \left(P(\varepsilon_v^d, \varepsilon_1^d) \cdot D\left(x^*, \underline{\sigma}(\varepsilon_1^d)\right) \cdot k^*(x) + P(\varepsilon_v^d, \varepsilon_2^d) \cdot D\left(x^*, \underline{\sigma}(\varepsilon_2^d)\right) \cdot k^*(x)\right) dx^* \end{Bmatrix}$$

Schematic relationship



[Missal, 2019]

Generic drift with sealing structure Model

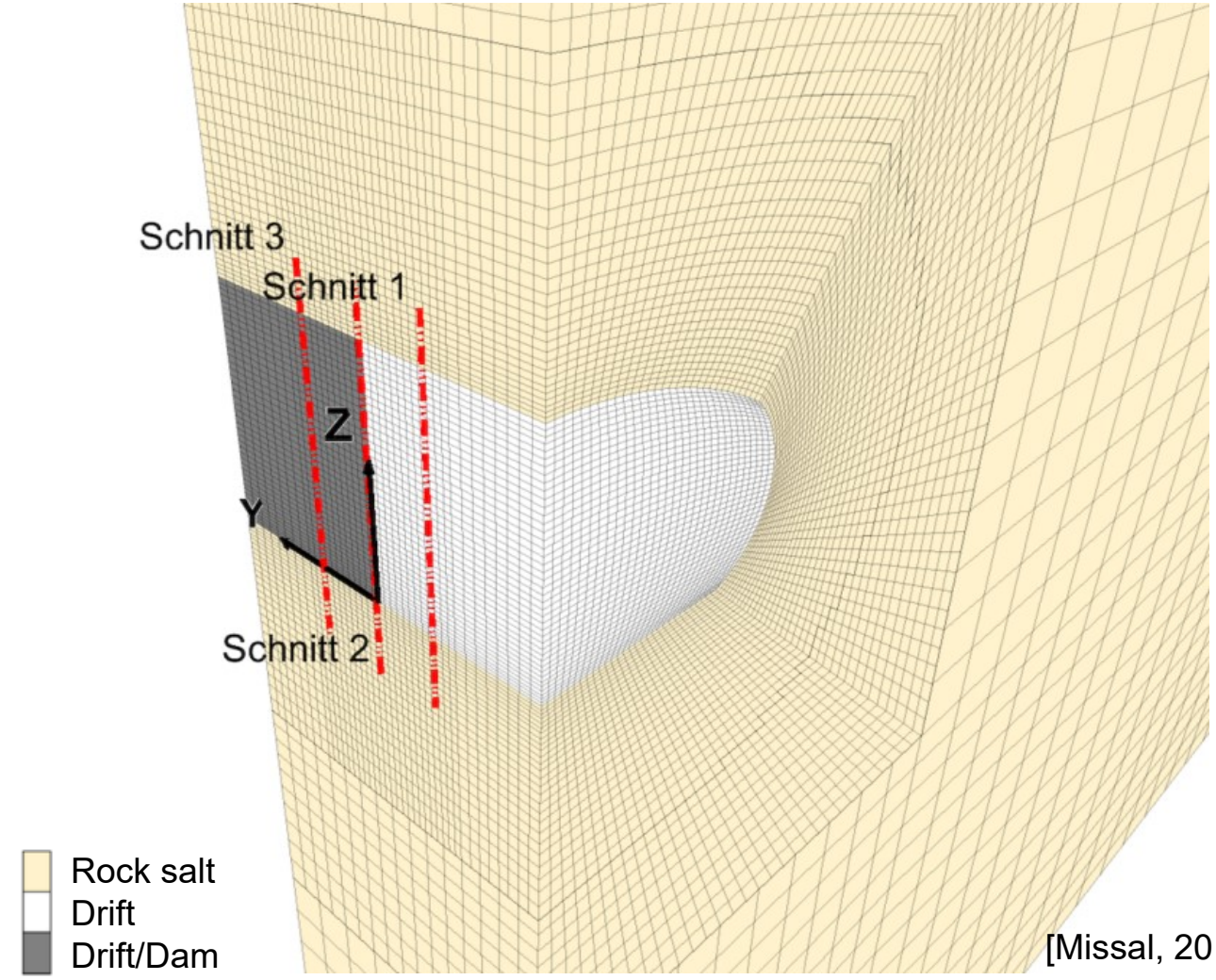
Dimensions of the model

- Width 60 m
- Height 75 m
- Length 8 m
- Zones 177.728

Simulation

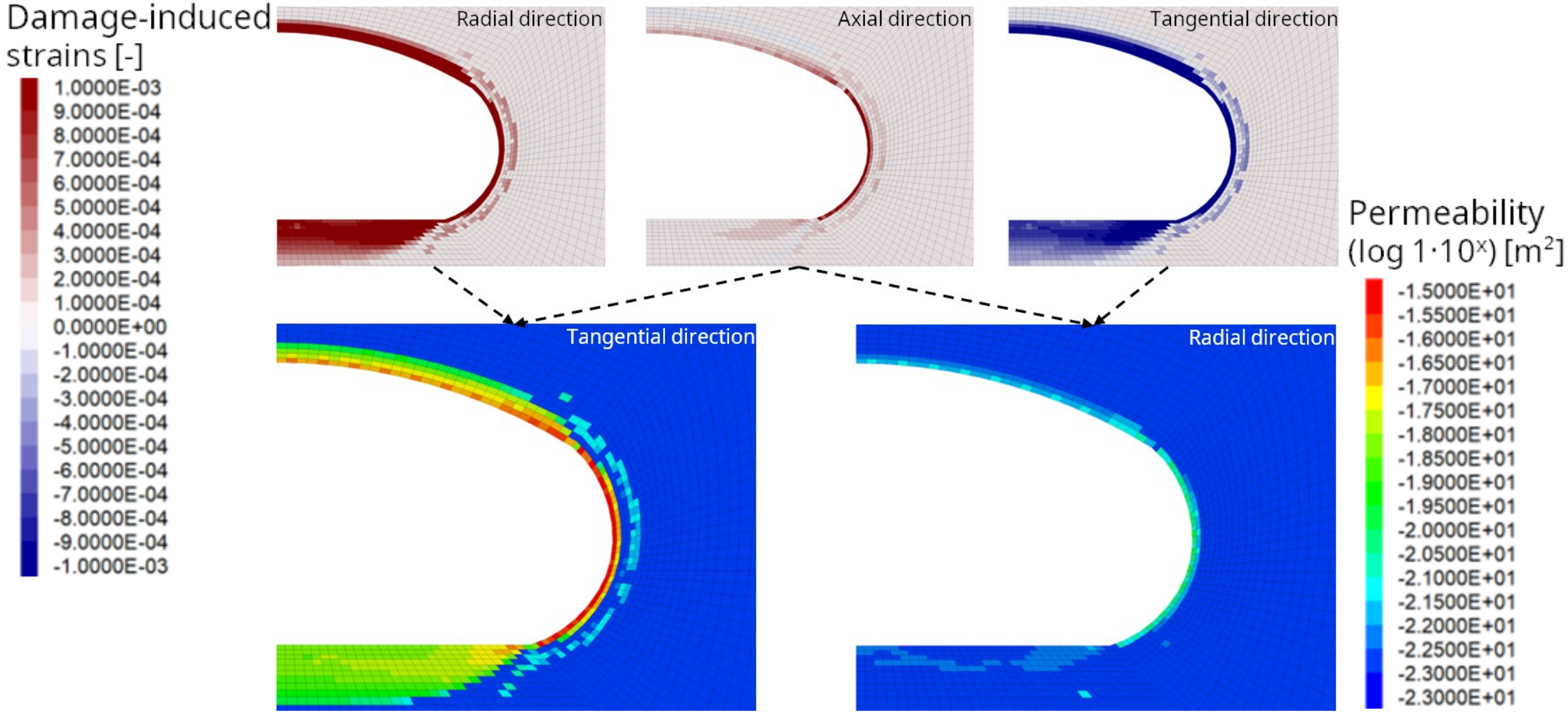
- Initial stress state
  Drift in 600 m depth → 14 MPa
- Excavation of the drift
- Construction of the sealing dam

Simulation time 50 years

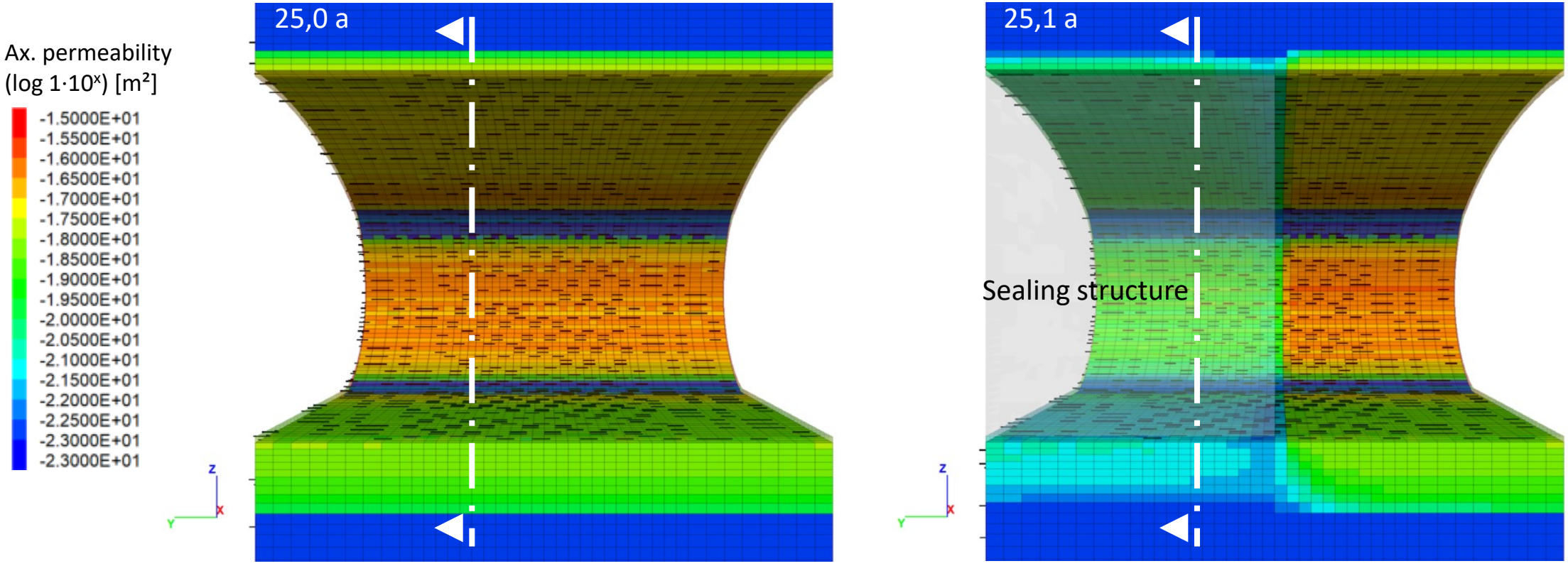


[Missal, 2019]

Generic drift with sealing structure
Damage and permeabilty after 25 years



Generic drift with sealing structure
Axial permeability before and after installing the dam



[Missal, 2019]

Conclusions

Extension of the constitutive model TUBSsalt

- Anisotropic permeability due to the damage-induced dilatancy
- The absolute crack widths are identified using the density function of the Rayleigh distribution
- Taking into account the associated damage component and the normal stress

More realistic description of the permeability in the EDZ
→ Optimization of the verification of the functionality of dam structures

But: These theoretical considerations have to be verified with a suitable test program

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Glückauf!

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