



Universiteit Utrecht

# On-going research programmes on salt at Utrecht University

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# Experimental Rock Deformation – HPT-laboratory

Mechanical behaviour and transport properties of Earth materials: experimental work and microstructural study of the active microscale processes, and microphysical and numerical modelling of these processes.

- 3 scientific staff (+ em.)
- 4 support staff
- 4 PostDocs
- 14 PhD candidates
- 3-6 MSc students



## HPT-laboratory: Salt projects

1. Long-term porosity-permeability evolution in and around **backfilled openings in a radioactive waste repository** in rock salt  
*(Bart van Oosterhout)*
2. Evolution of the mechanical/transport properties of rock salt under simulated **cavern wall conditions during cyclical hydrogen storage**  
*(Johanna Heeb)*
3. Multi-scale **validation of constitutive models for rock salt creep** behavior and application to field-scale numerical models:  
i) experimental *(Vangelis Dialeismas)*, ii) numerical *(Gaurav Jain)*



# HPT-laboratory: Salt projects

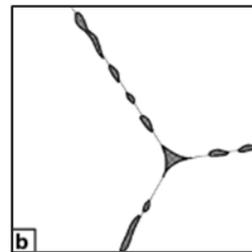
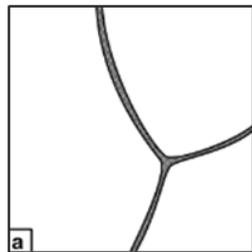
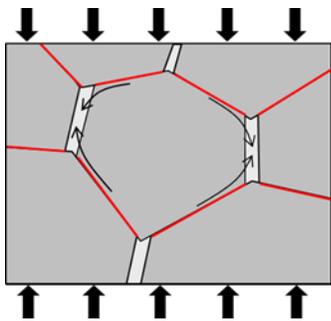
All focus on issues that need to be resolved

**Developments in salt mechanics research:**  
An overview

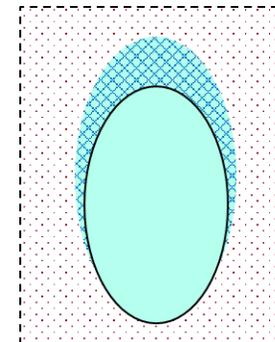
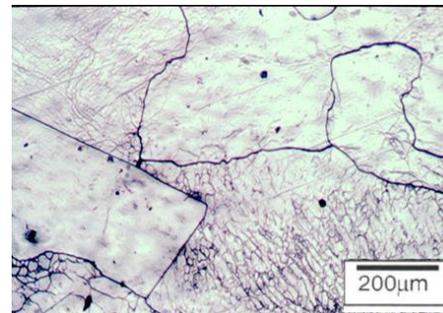
**Chris Spiers**

Research still needed on:

- Threshold stress for p-solution
- Effects of recrystallization on creep
- Chemical coupling: damage, permeation and p-solution
- Effects of heterogeneities / anisotropy ... + P-T-Stress-Humidity cycling



SCHENK & URAI 2005



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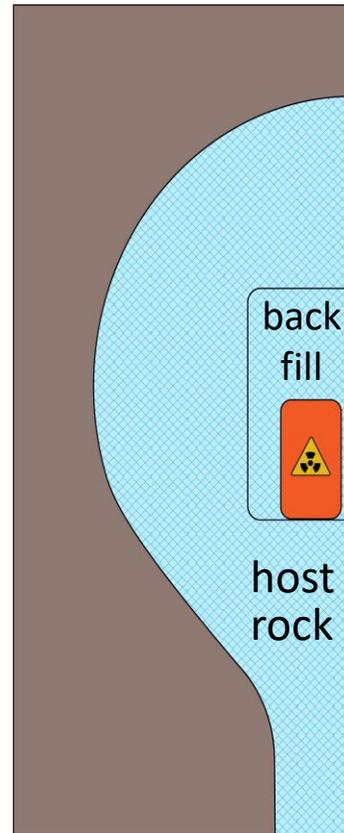
# 1. Backfilled openings in a radioactive waste repository

Key question: on what timescales will the permeability of the backfill reach values of undisturbed rocksalt?

How does the dense rock salt around a backfilled repository converge?  
*Deformation mechanisms, effect of damage, threshold stress*

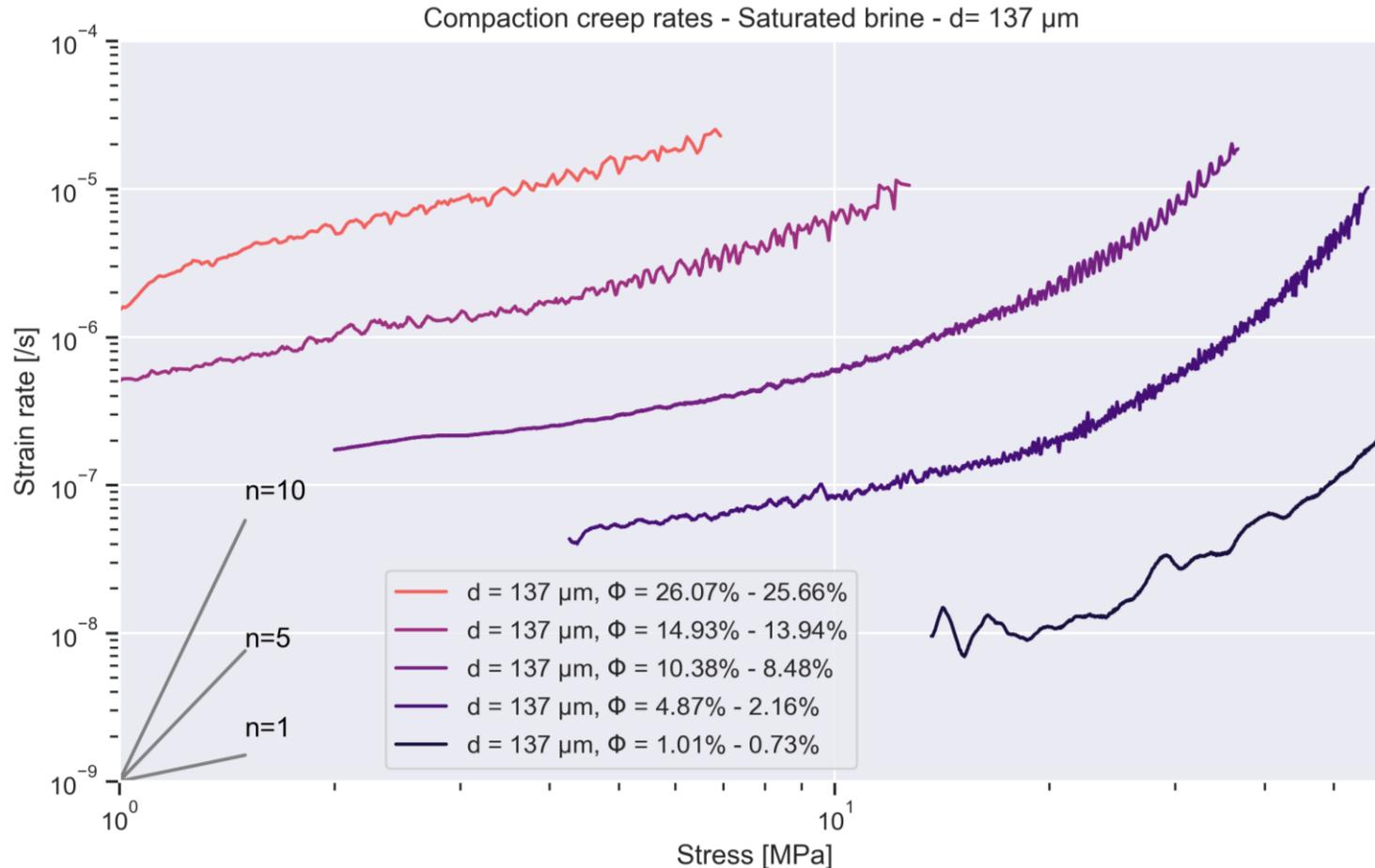
How does the backfill in the repository compact?  
*Effect of stress, grain size and porosity*

Which mechanisms play a role in the long-term reduction of permeability in the backfill?  
*Long term healing*



# 1. Backfilled openings in a radioactive waste repository

## Effect of porosity



- Grain size of  $137 \pm 12 \mu\text{m}$
- 5 relaxation phases at 26-15-10-5-1% porosity
- Porosity 25  $\rightarrow$  1 %
- Strain rates drop 3-4 orders of magnitude

$$\dot{\epsilon} = A\sigma^n$$

Low  $\sigma$ :

$$n = 0.8 - 1.1$$

High  $\sigma$ , low  $\phi$ :

$$n = 4.7 - 5.1$$



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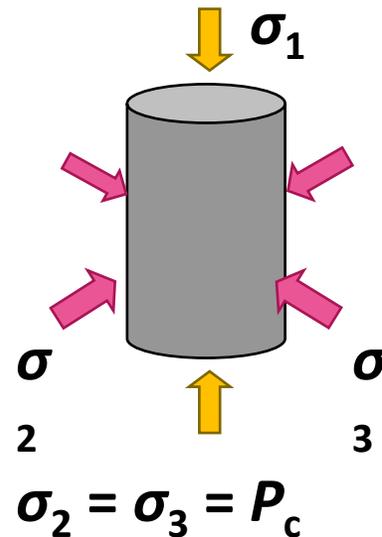




## 2. Cavern wall conditions during cyclical hydrogen storage

### Experimental approaches

- Triaxial deformation experiments coupled with permeability measurements (i.e. measure of damage or cracking)
- Natural rock salt: damaged (low  $P_c$ , high  $\sigma_1$ ) and intact (high  $P_c$ , low  $\sigma_1$ )
- $T = \text{room T}$ ;  $P_f = 2\text{-}5 \text{ MPa}$  (argon or brine)



### Simulating specific scenarios:

- Daily pressure changes + periods of no activity
- Multiple cycles per hour
- Temperature changes and/or overpressurisation

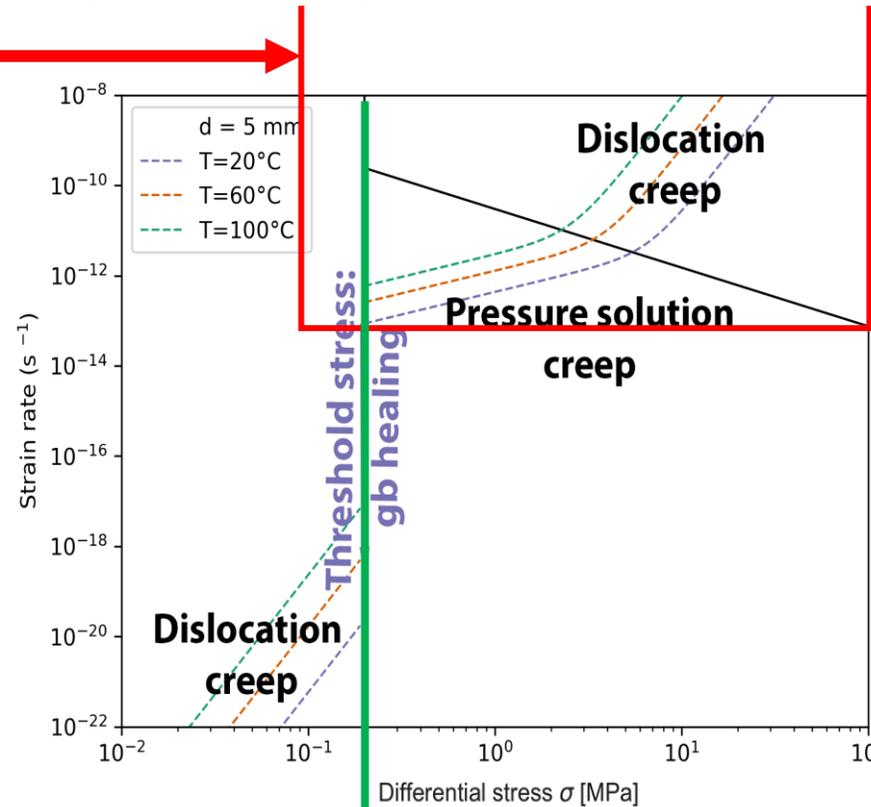
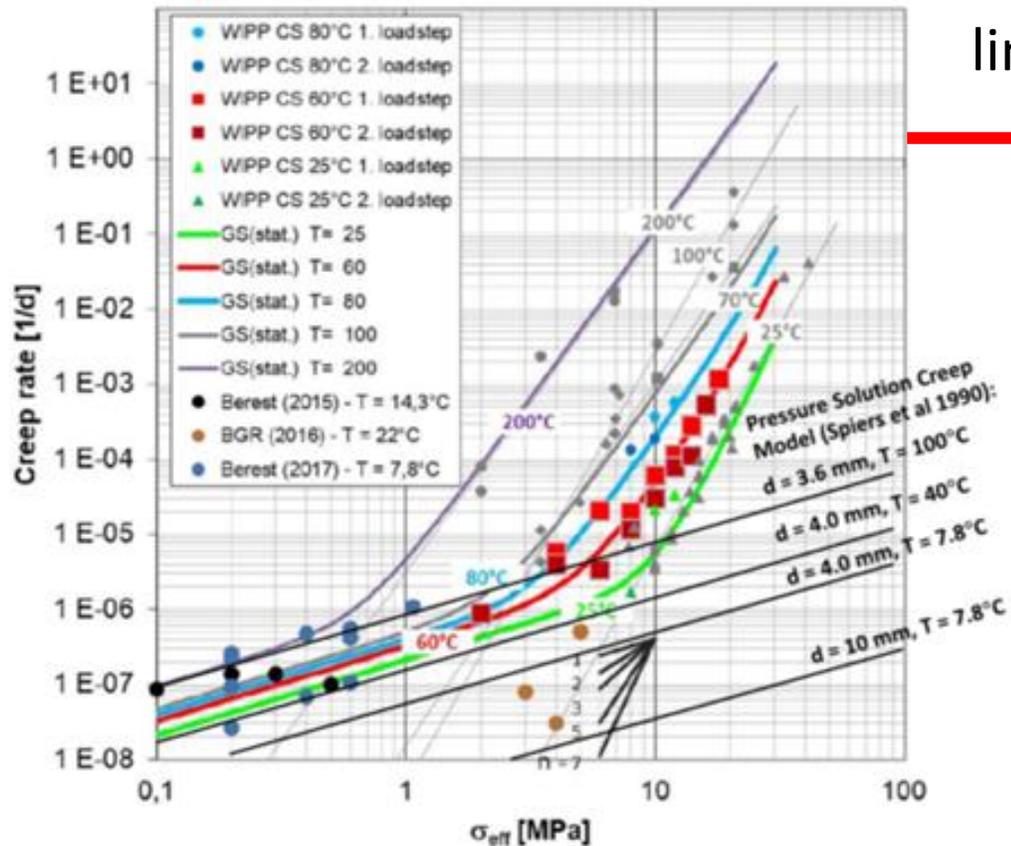
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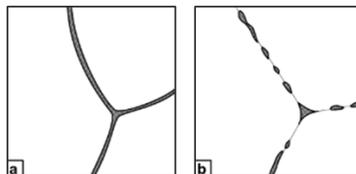
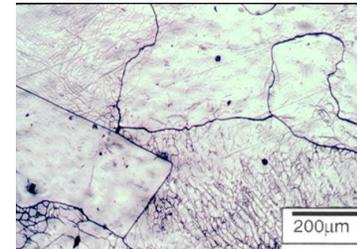


# 3. Validation of constitutive models for rock salt creep

Non-linear (dislocation) creep at high  $\sigma$ ,  
linear (p-solution) creep at low  $\sigma$



Dynamic recrystallization



SCHENK & URAI 2005

Threshold stress?

# 3. Validation of constitutive models for rock salt creep

## Experimental approach

Quantitative law for linear creep for Dutch Zechstein

Determine threshold stress

Effects of recrystallization on creep

Upscaling of lab creep laws to mesh and salt-unit scales

## Numerical model approach

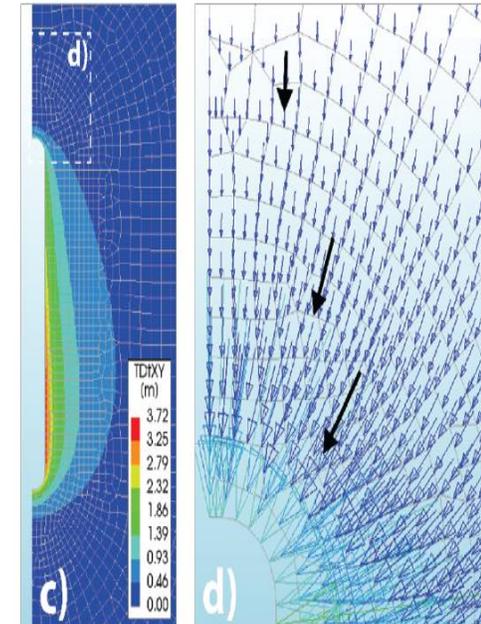
Salt cavern model implementing microphysically based creep laws

Prediction of convergence and surface subsidence

Cavern integrity analysis in :  
Operation and abandonment stages

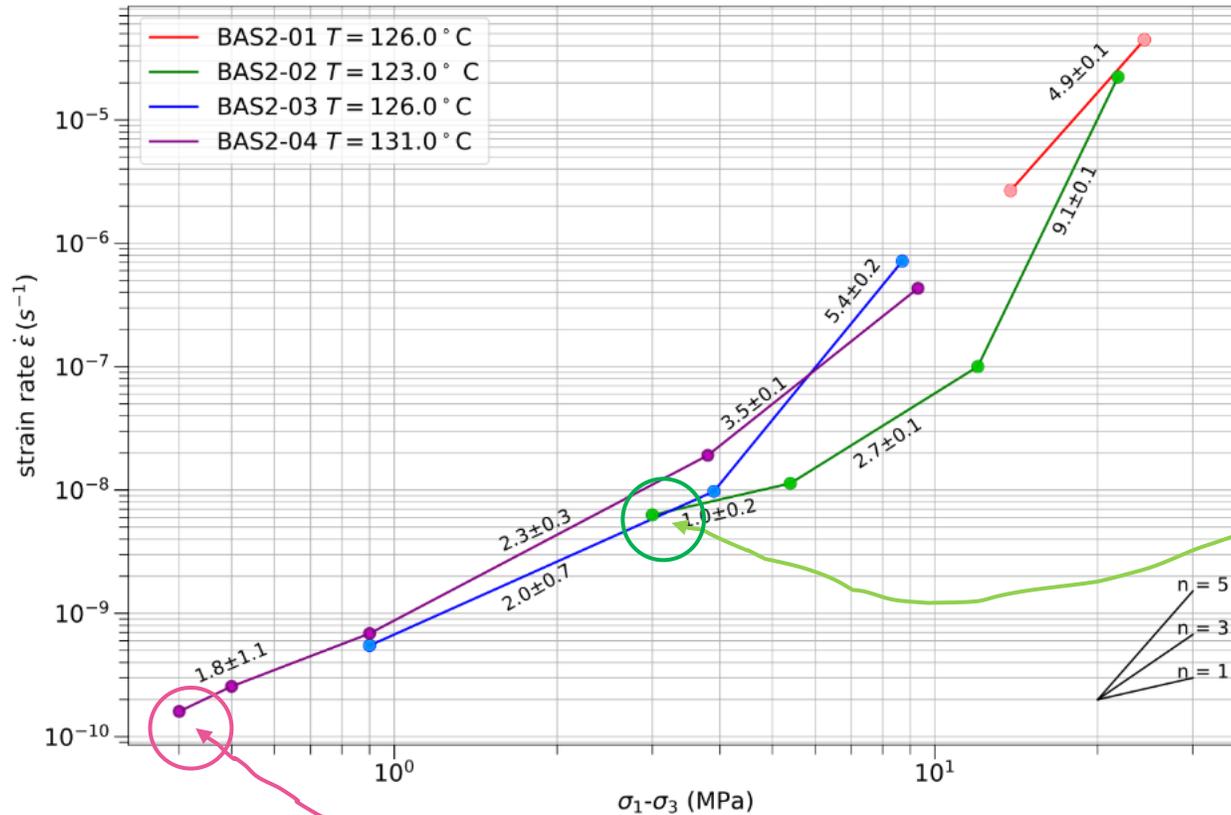


Simulation 3: threshold = 0.07 MPa

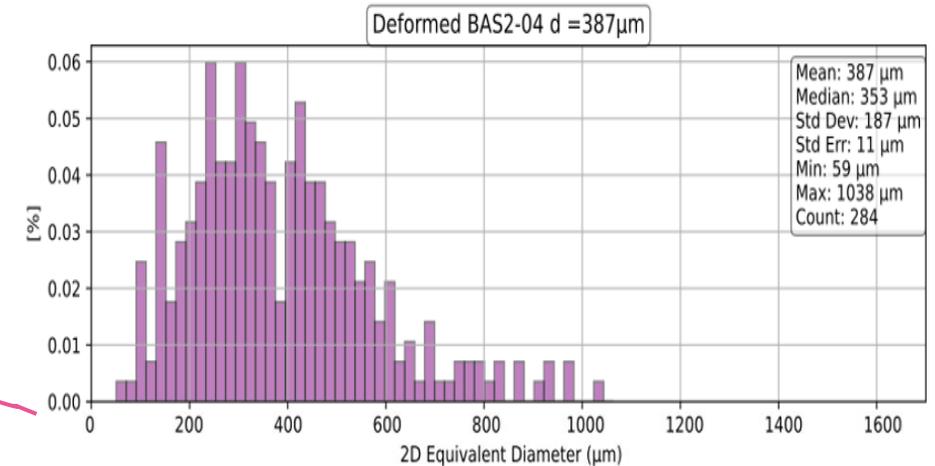
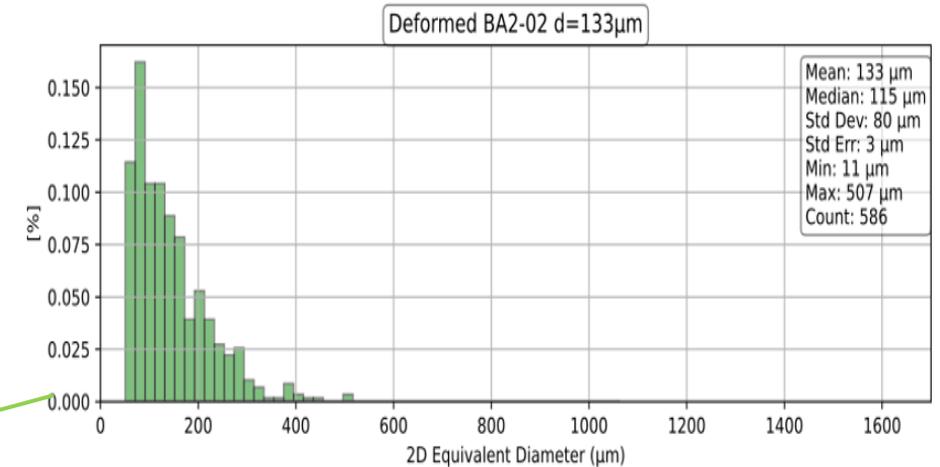


Hunfeld et.al 2022

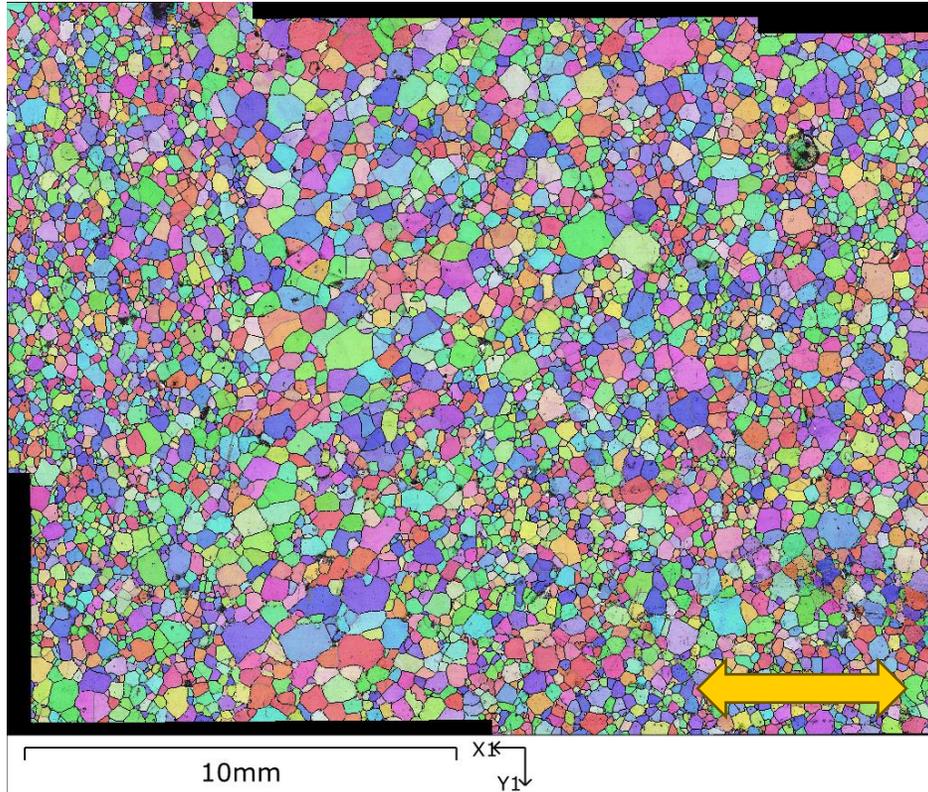
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Samples from Barradeel  
(grain size 150-400  $\mu\text{m}$ )

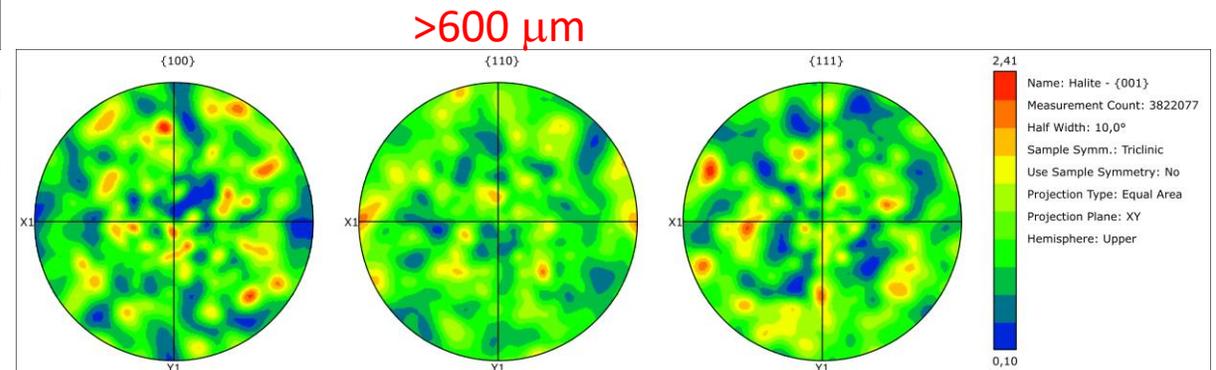
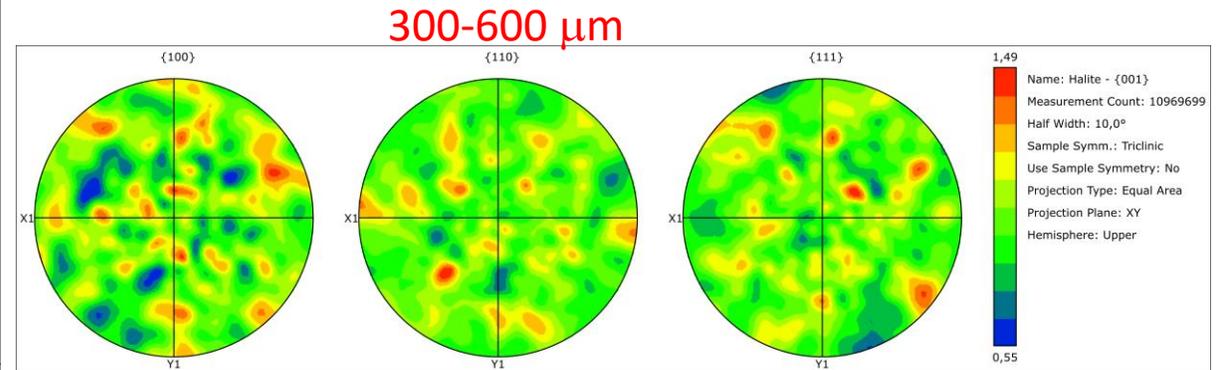
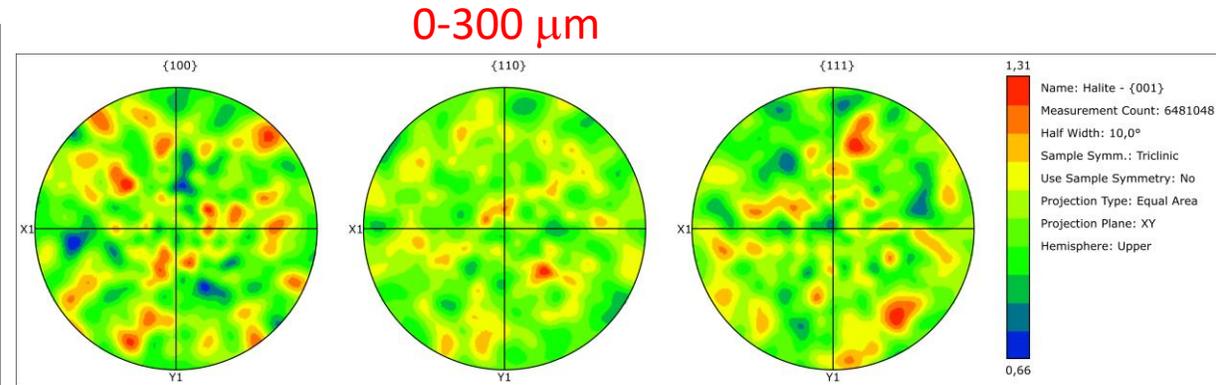


# 3. Validation of constitutive models for rock salt creep

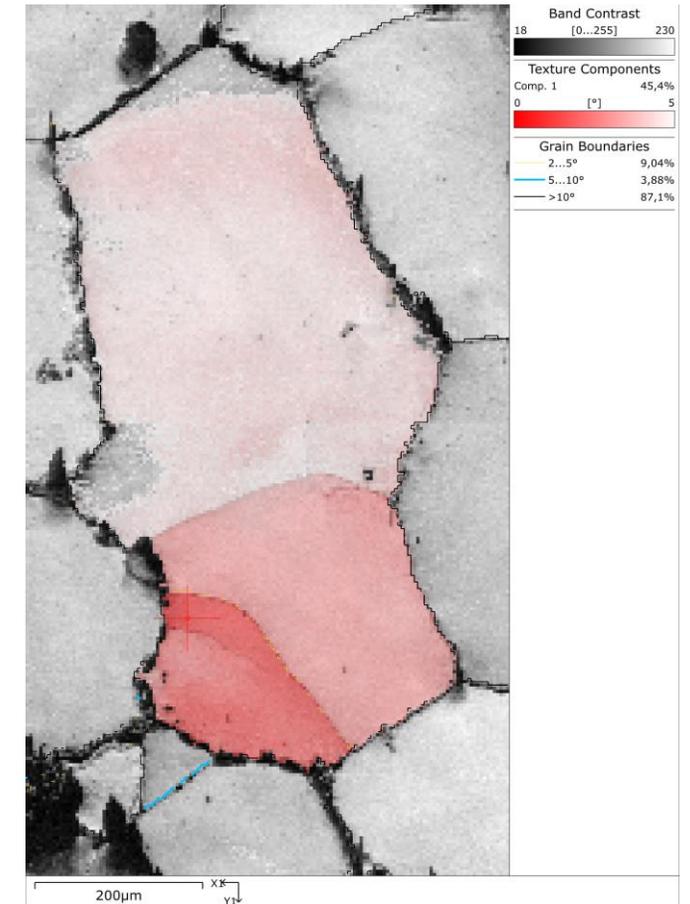
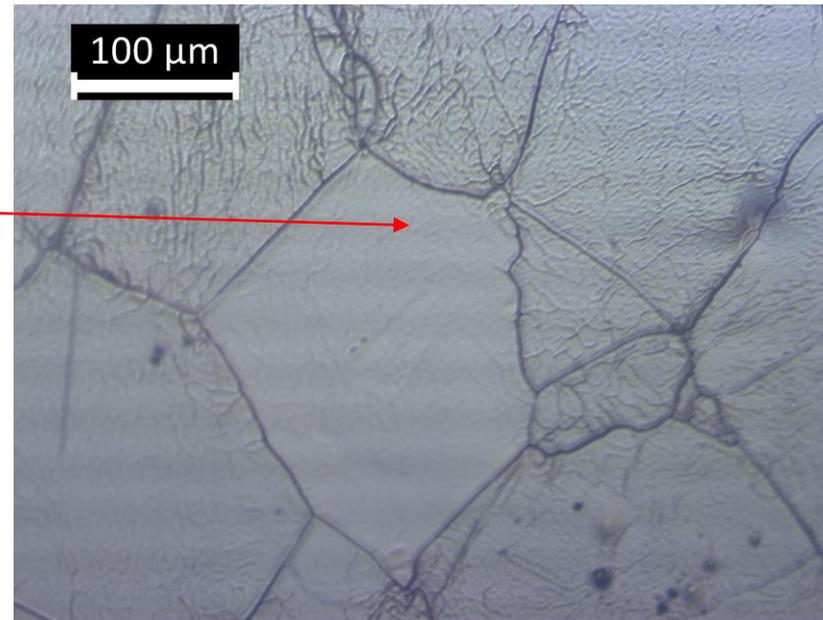
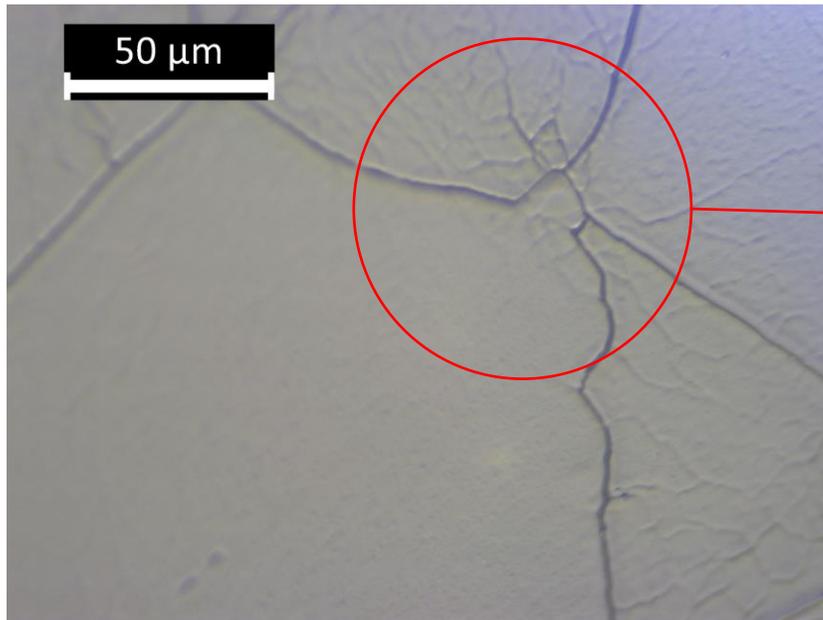


Experimentally deformed  
**BAS2-02**

EBSD: weak LPO  
(@strain 4%)



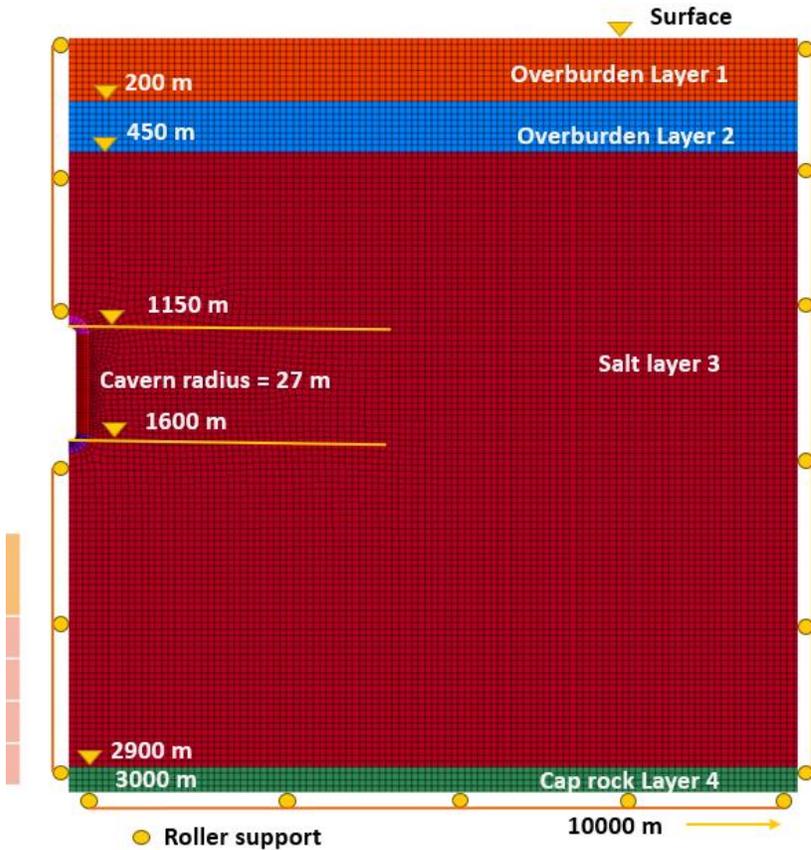
### 3. Validation of constitutive models for rock salt creep



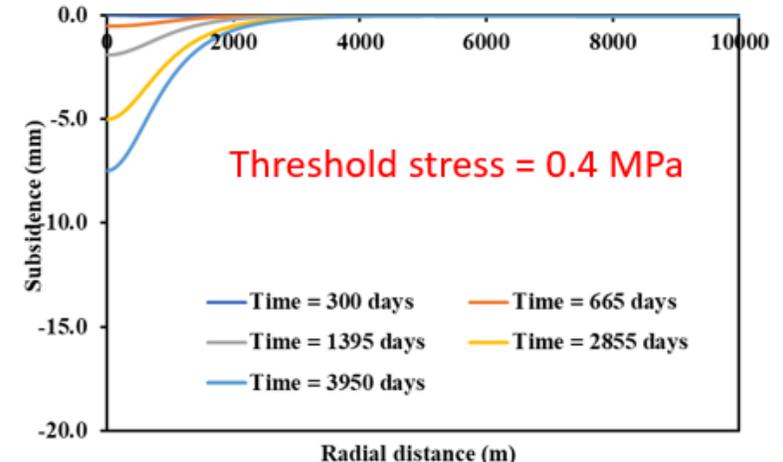
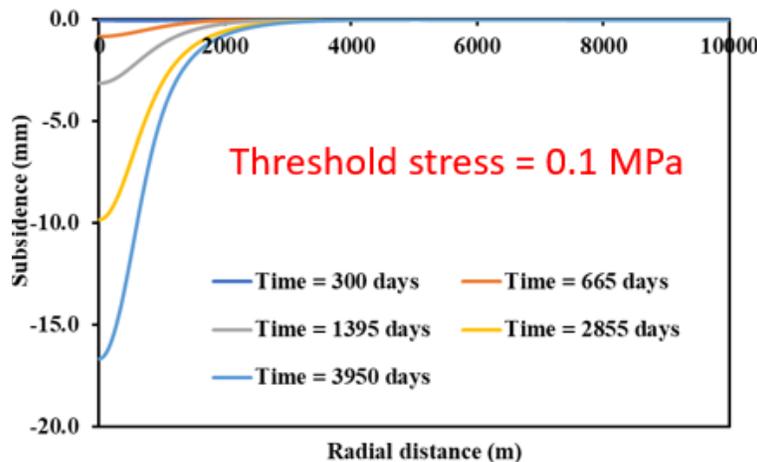
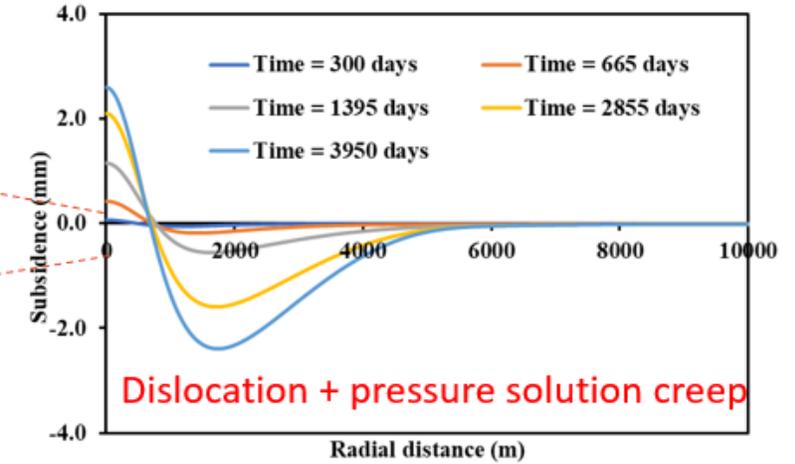
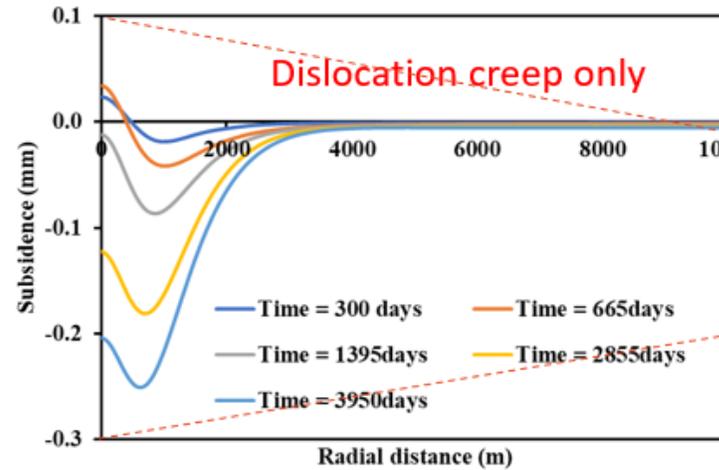
Experimentally deformed  
**BAS2-02**

- Irregular grain boundaries
- Indentation-like structures
- subgrains

# 3. Validation of constitutive models for rock salt creep



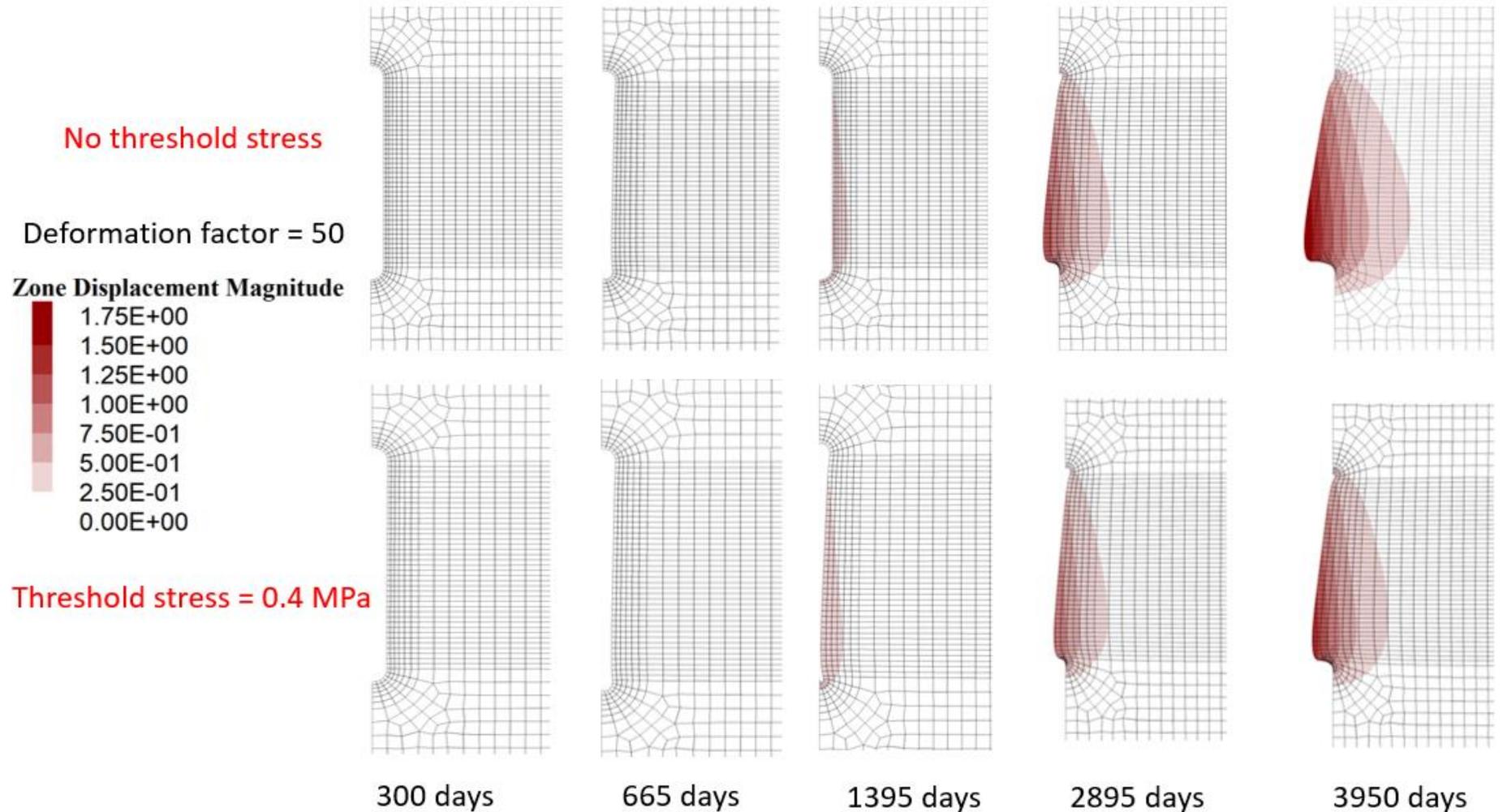
FLAC 2D



Subsidence

### 3. Validation of constitutive models for rock salt creep

Cavern evolution with time





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