Practical considerations on the abandonment of a cavern field

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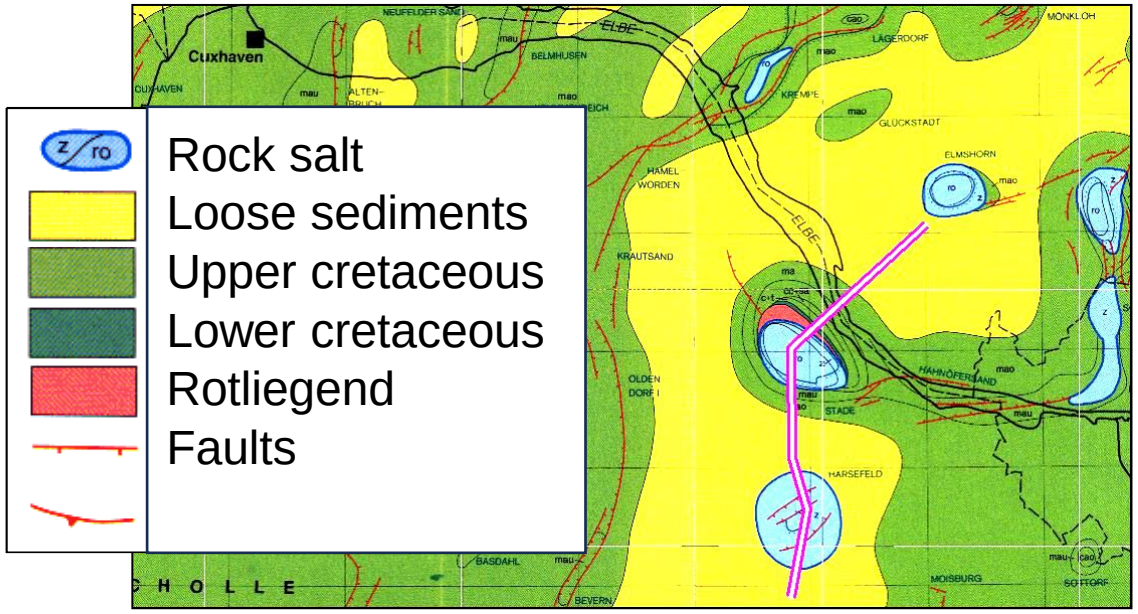
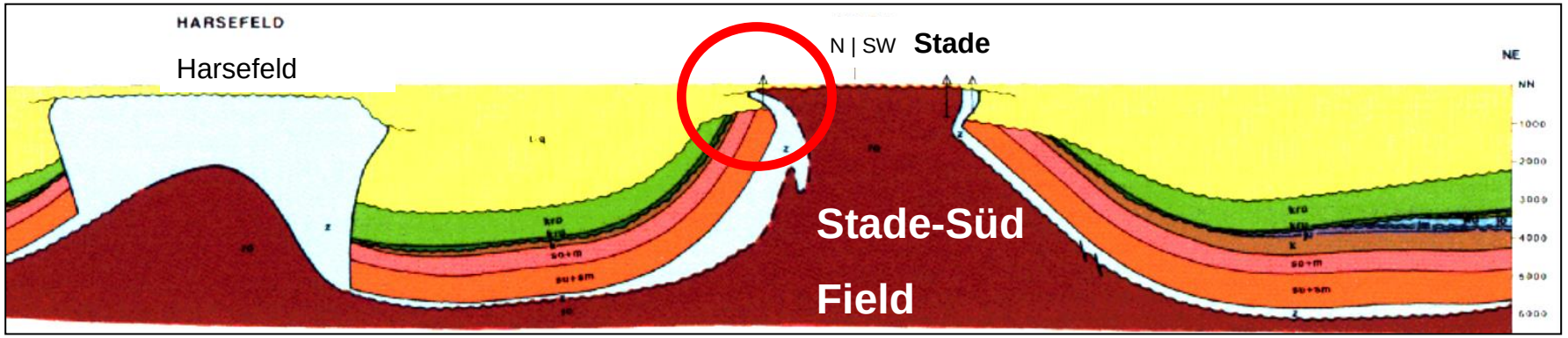
Geologic situation around the Stade salt dome

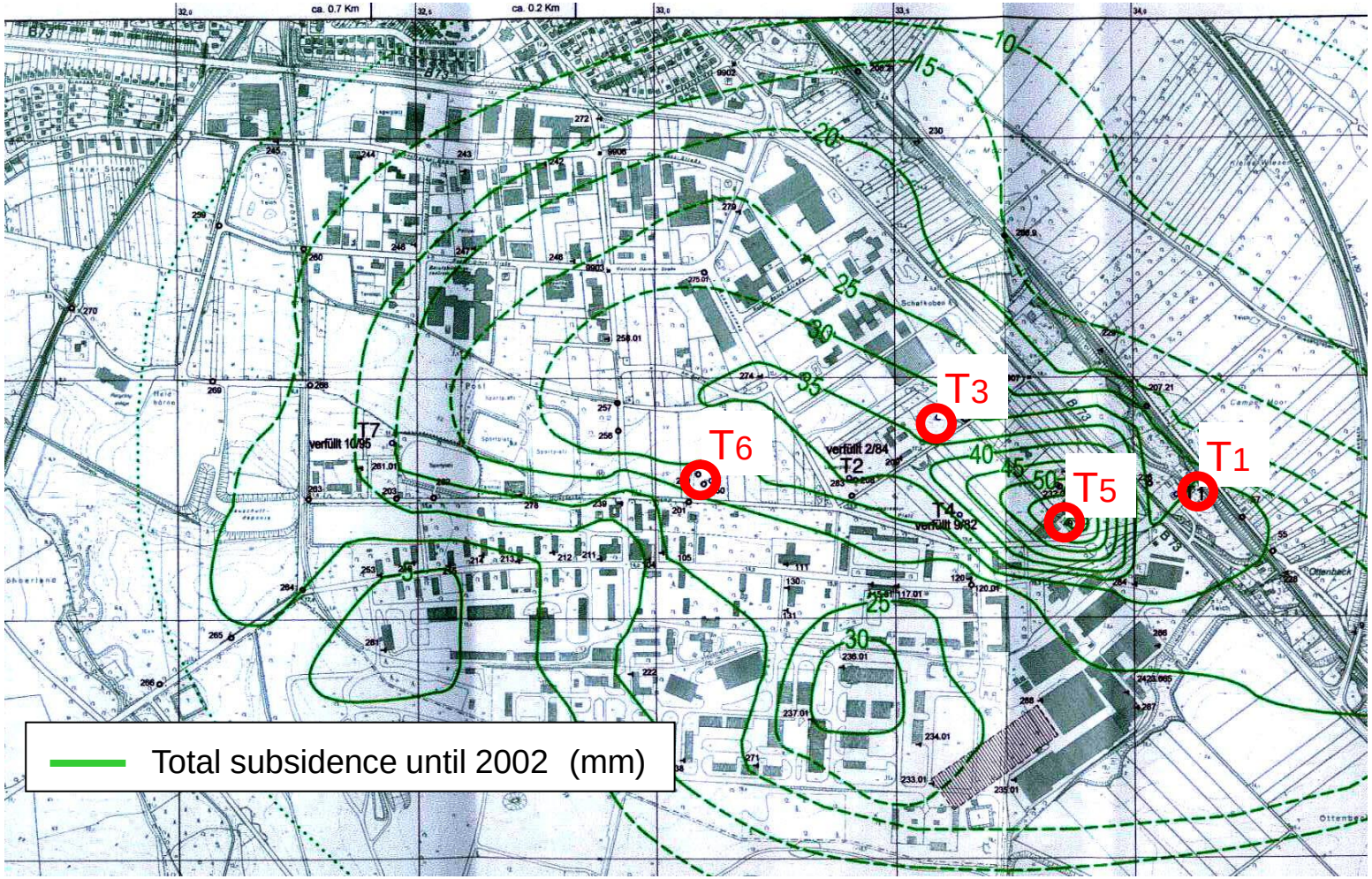


Geological Map from:

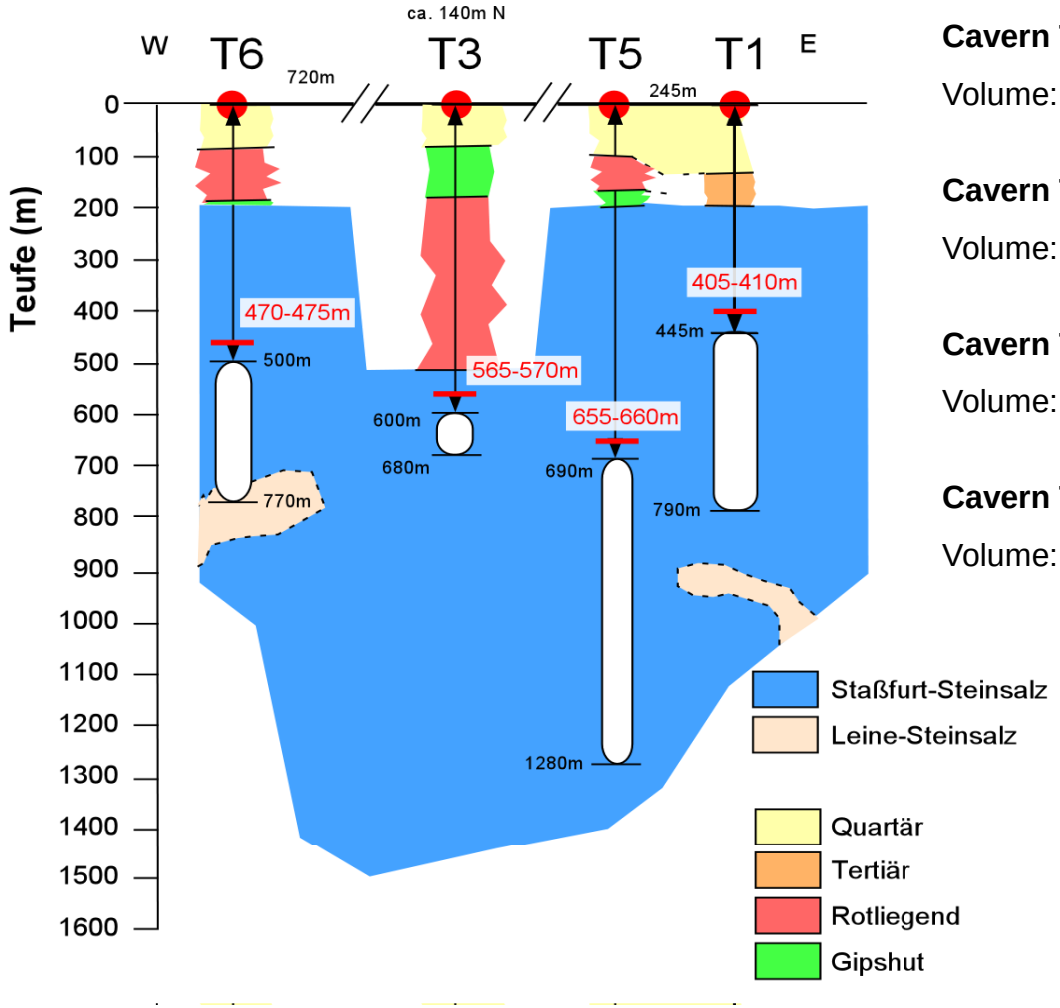
Geotektonischer Atlas von Nordwest-Deutschland, (BGR, 1999)



Subsidence during operation



Caverns that were to be abandoned



Cavern T1

Volume: **1,35 Mio. m³**

Cavern T3

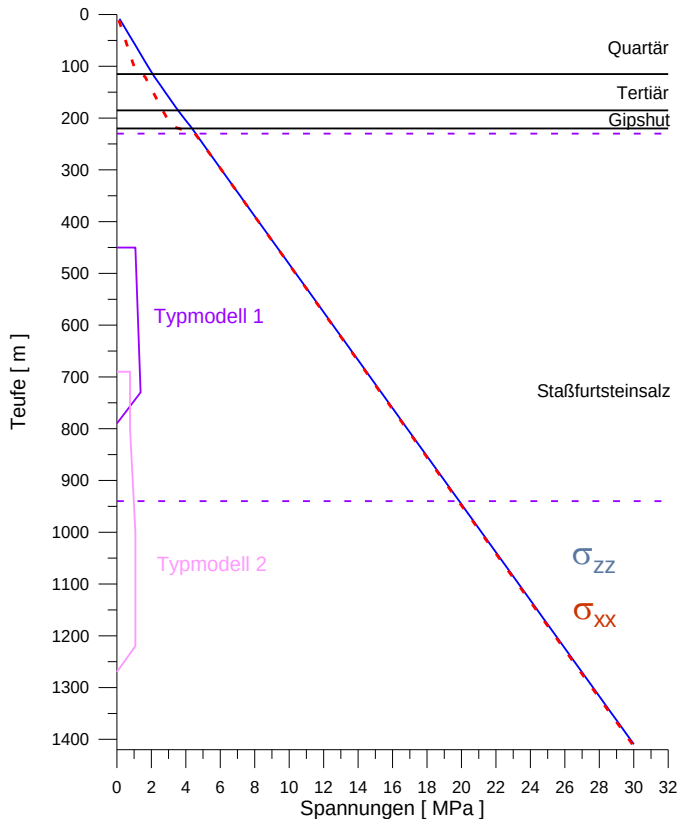
Volume: **ca. 0,08 Mio. m³**

Cavern T5

Volume: **1,54 Mio. m³**

Cavern T6

Volume: **1,053 Mio. m³**



Modelling assumptions back in 2004

Model layout: 2D axissymetric, type caverns

Triaxial Short Term Strength:

$$(\sigma_{vM})_{max} = \sigma_D + \frac{\sigma_{MAX} - \sigma_D}{\sigma_3 + \sigma_\phi} \cdot \sigma_3$$

Site specific parameters: σ_D = 24 MPa (uniaxial strength) σ_{MAX} = 63 MPa σ_ϕ = 5 MPa

Utilization factor:

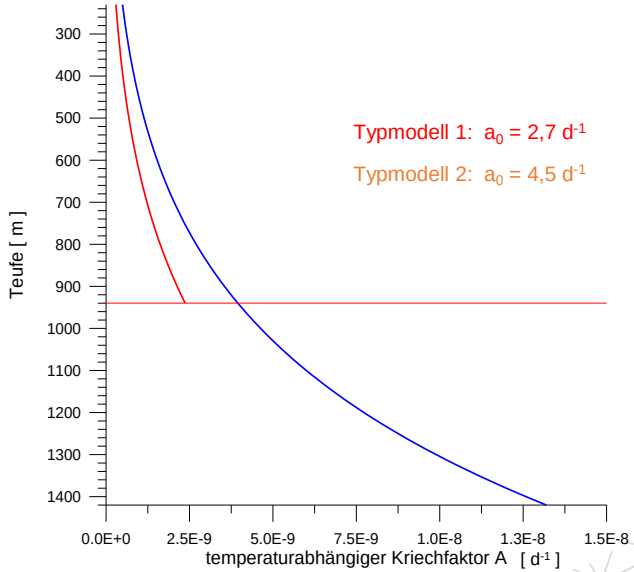
$$\eta = \frac{\sigma_{vM}}{(\sigma_{vM})_{max}}$$

Stationary creep:

$$\dot{\varepsilon}_C = A \cdot \sigma^n \qquad A = A_0 \cdot \exp\left(-\frac{Q}{R \cdot T}\right)$$

single exponent power law

A_0 = 2,7 d^{-1} (T1) 4,5 d^{-1} (T2) n = 5 and Q/R = 6519 K

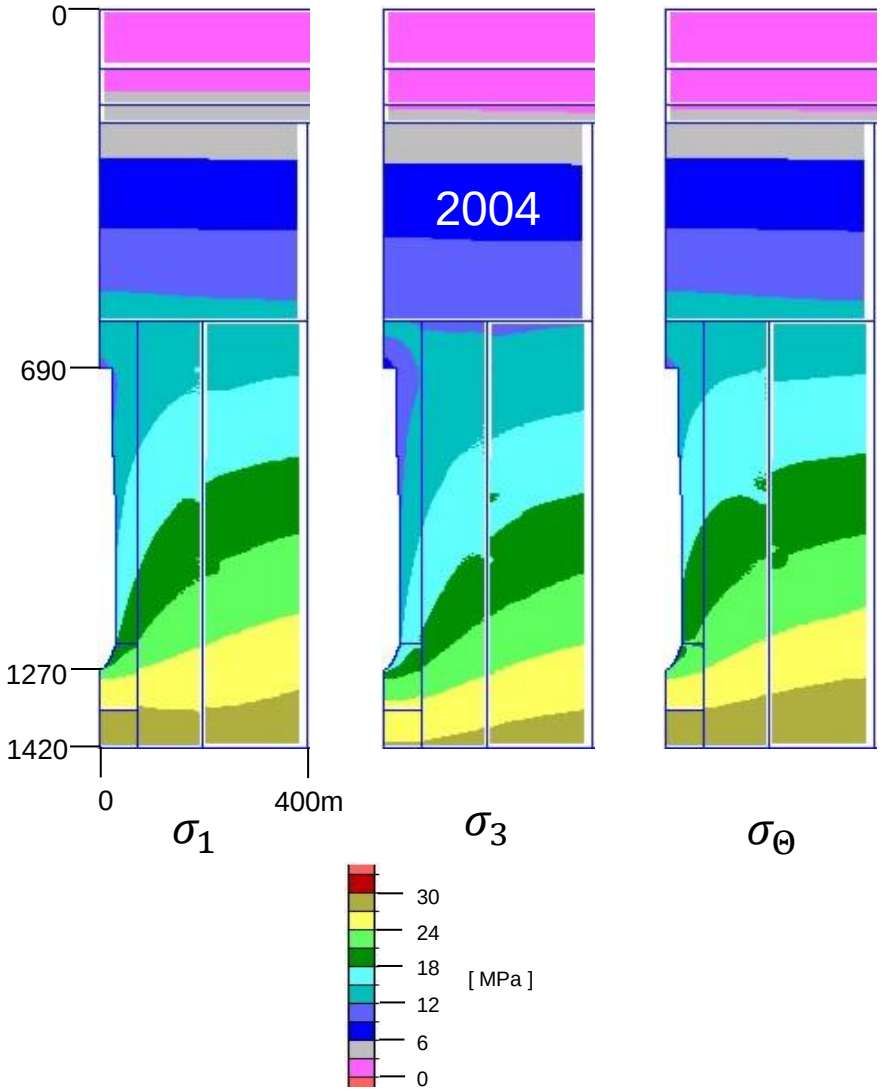


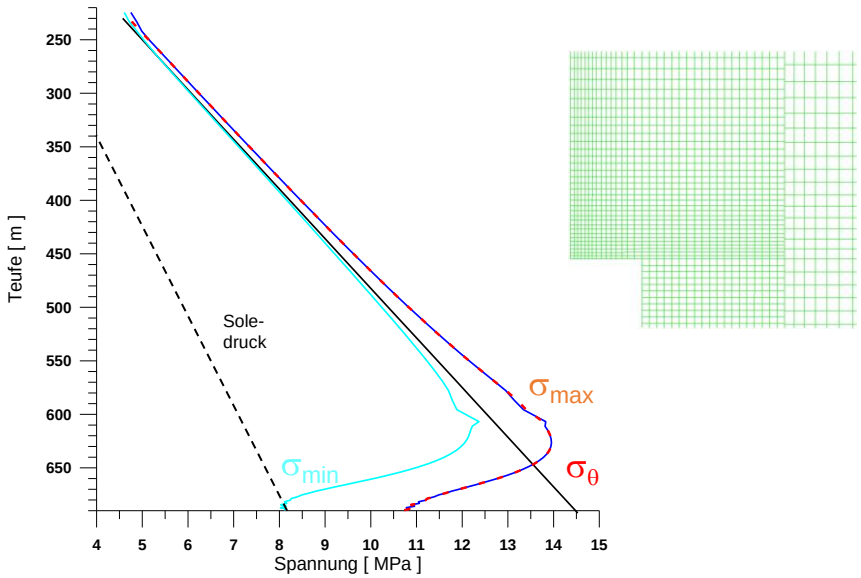
Darcy flow approximation:

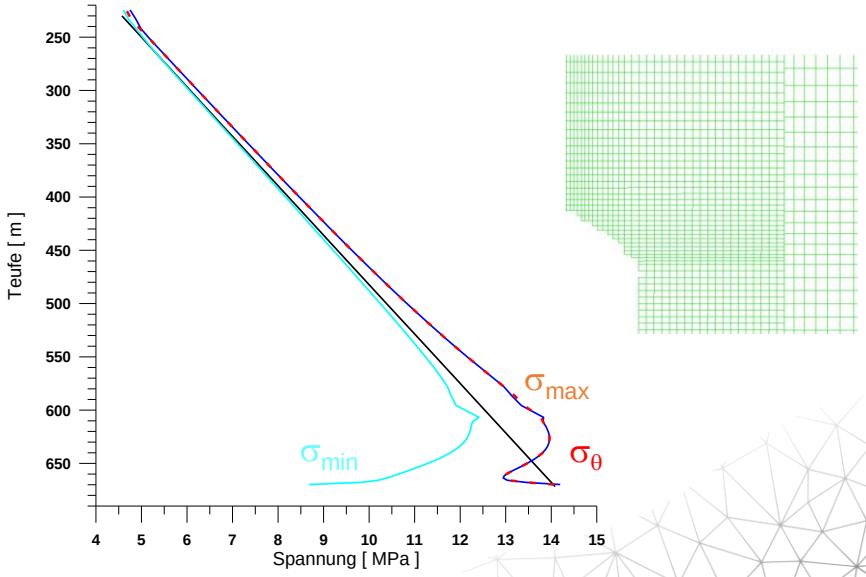
$$\frac{\Delta V}{\Delta t} = \frac{K}{\eta}\frac{A_E}{I_E}\Delta p$$

Constant permeability

Modeled stress state in 2004 and roof stability







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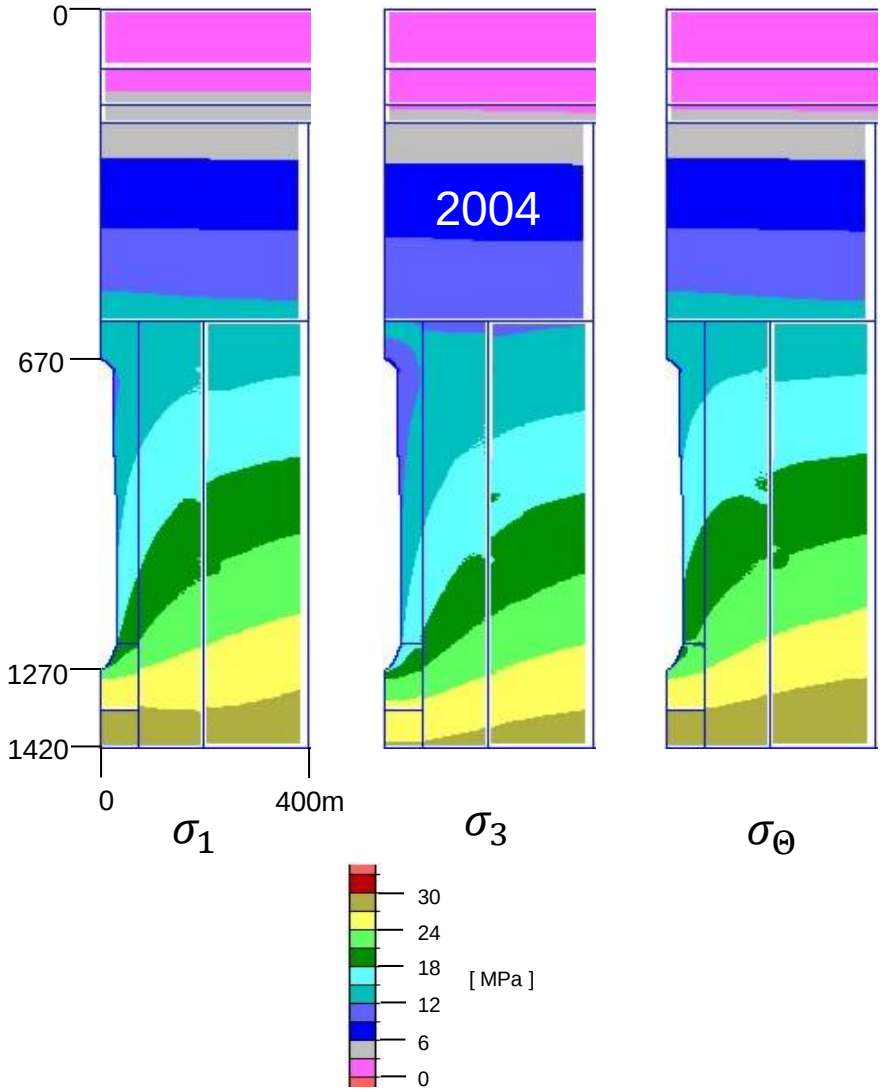
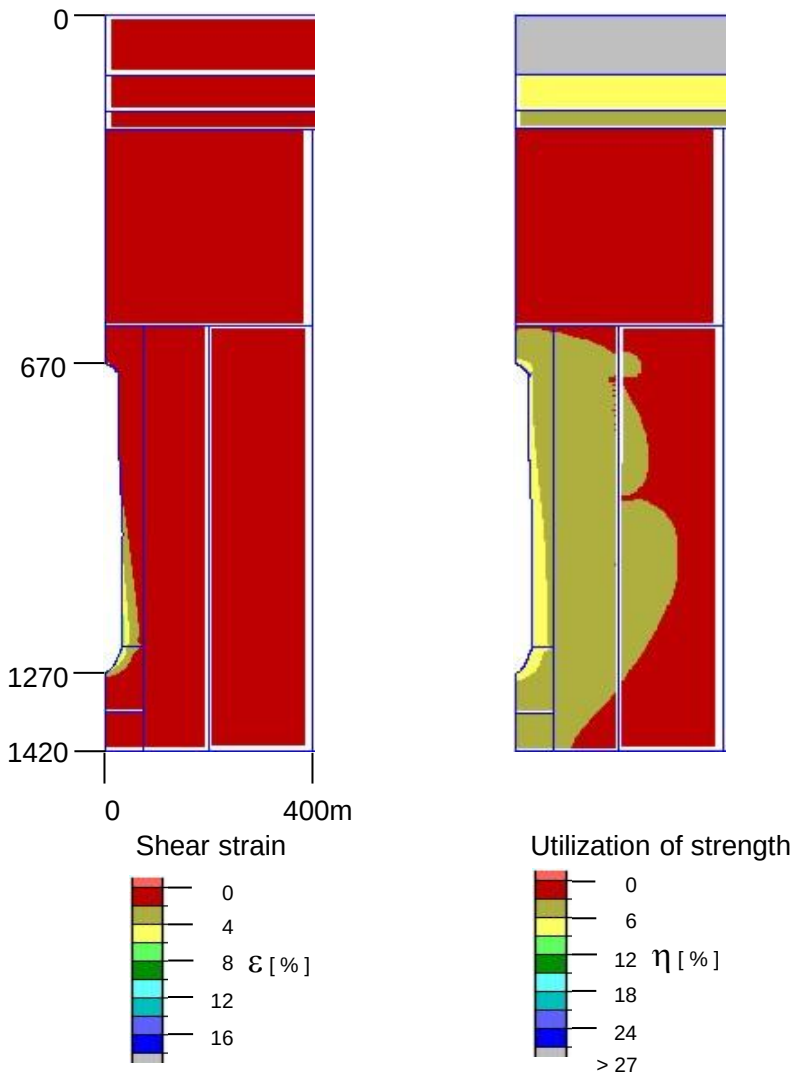
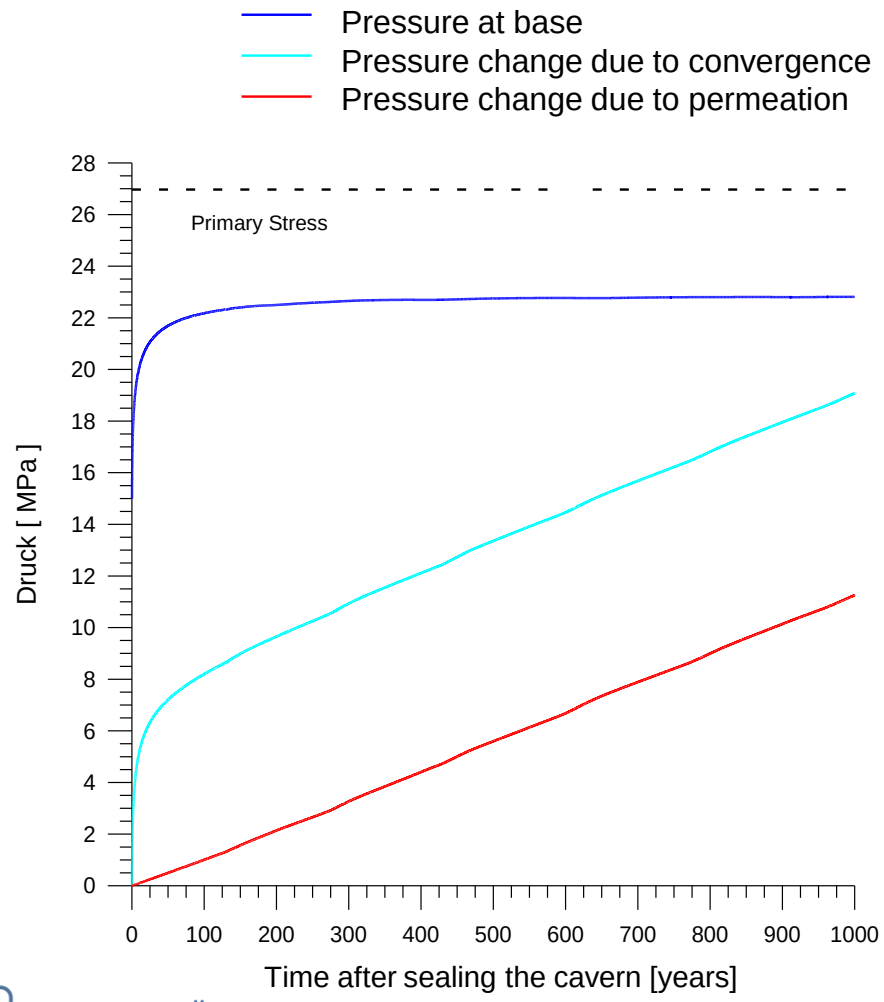
Mechanical integrity



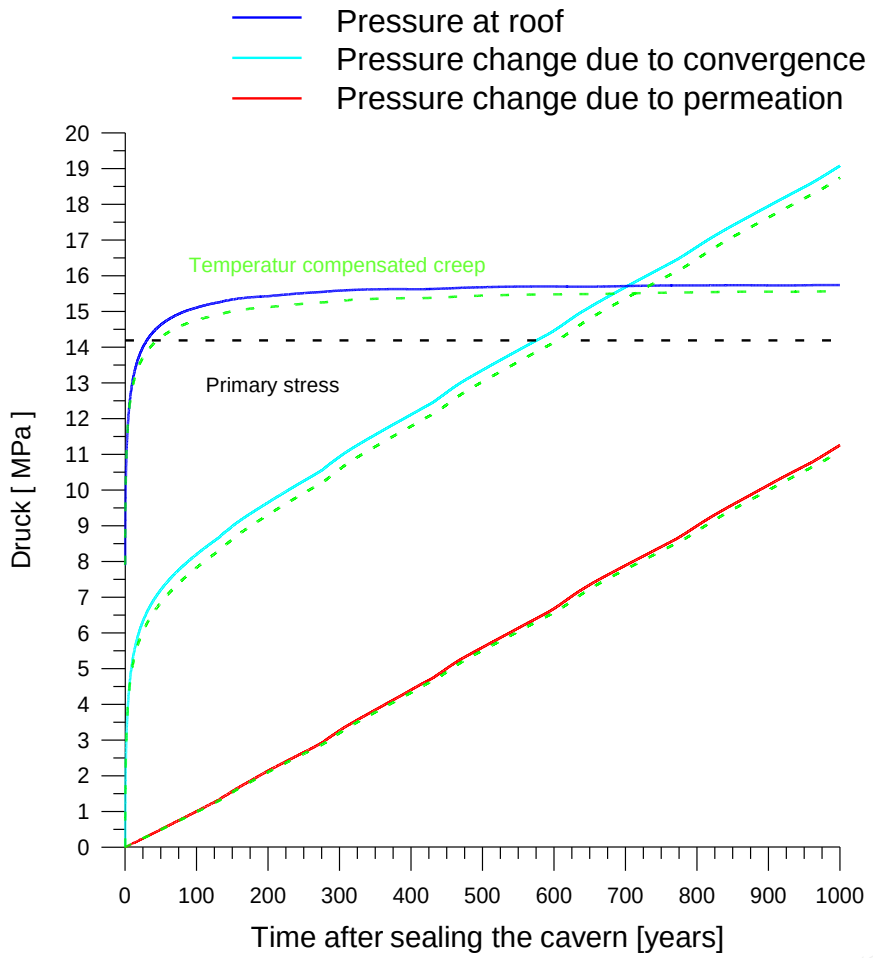


Pressure increase due to convergence

Pressure at the cavern base (1270 m) after sealing

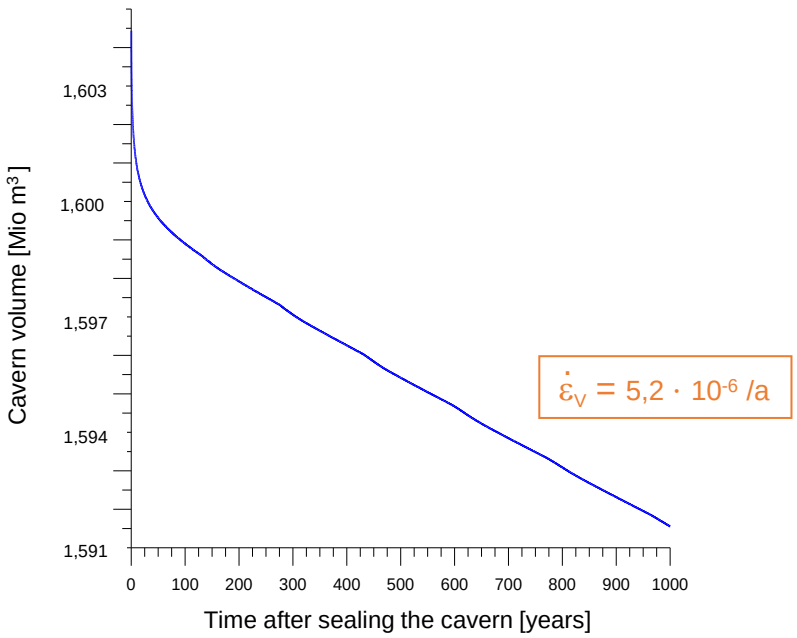


Pressure at the cavern roof (670 m) after sealing

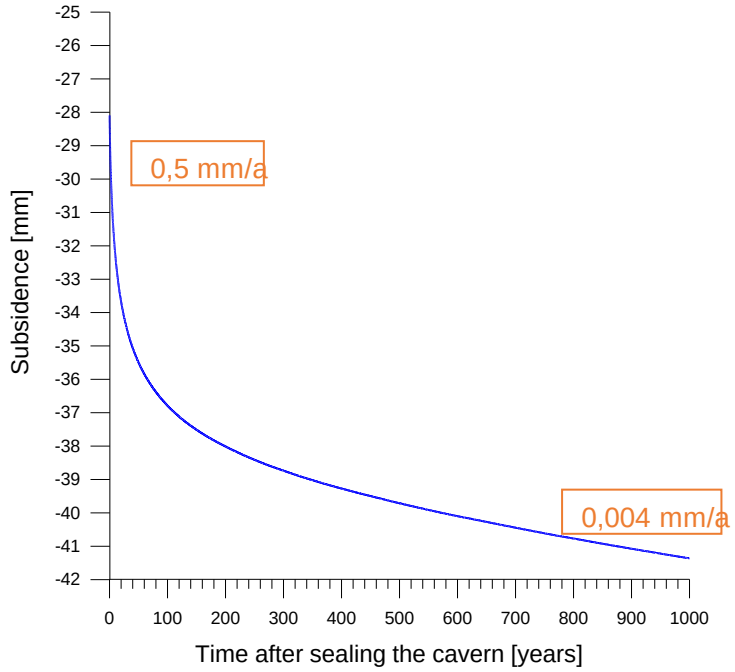


Convergence and subsidence

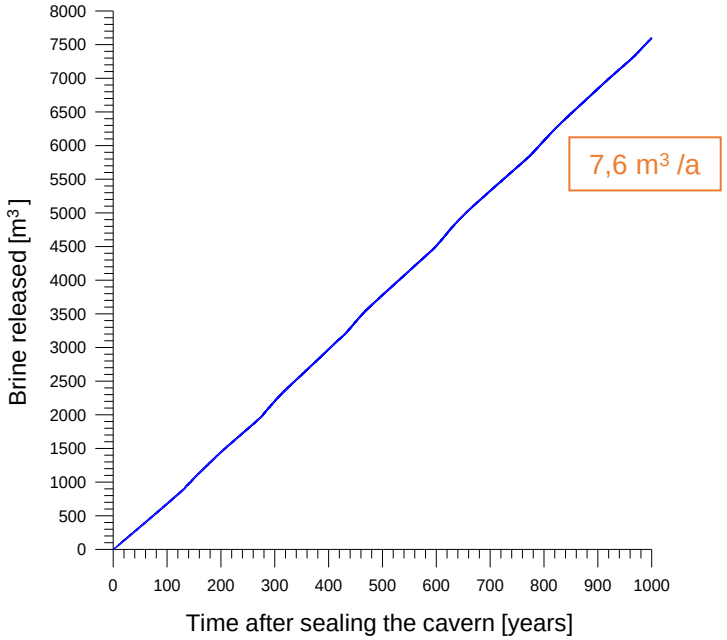
Volume convergence



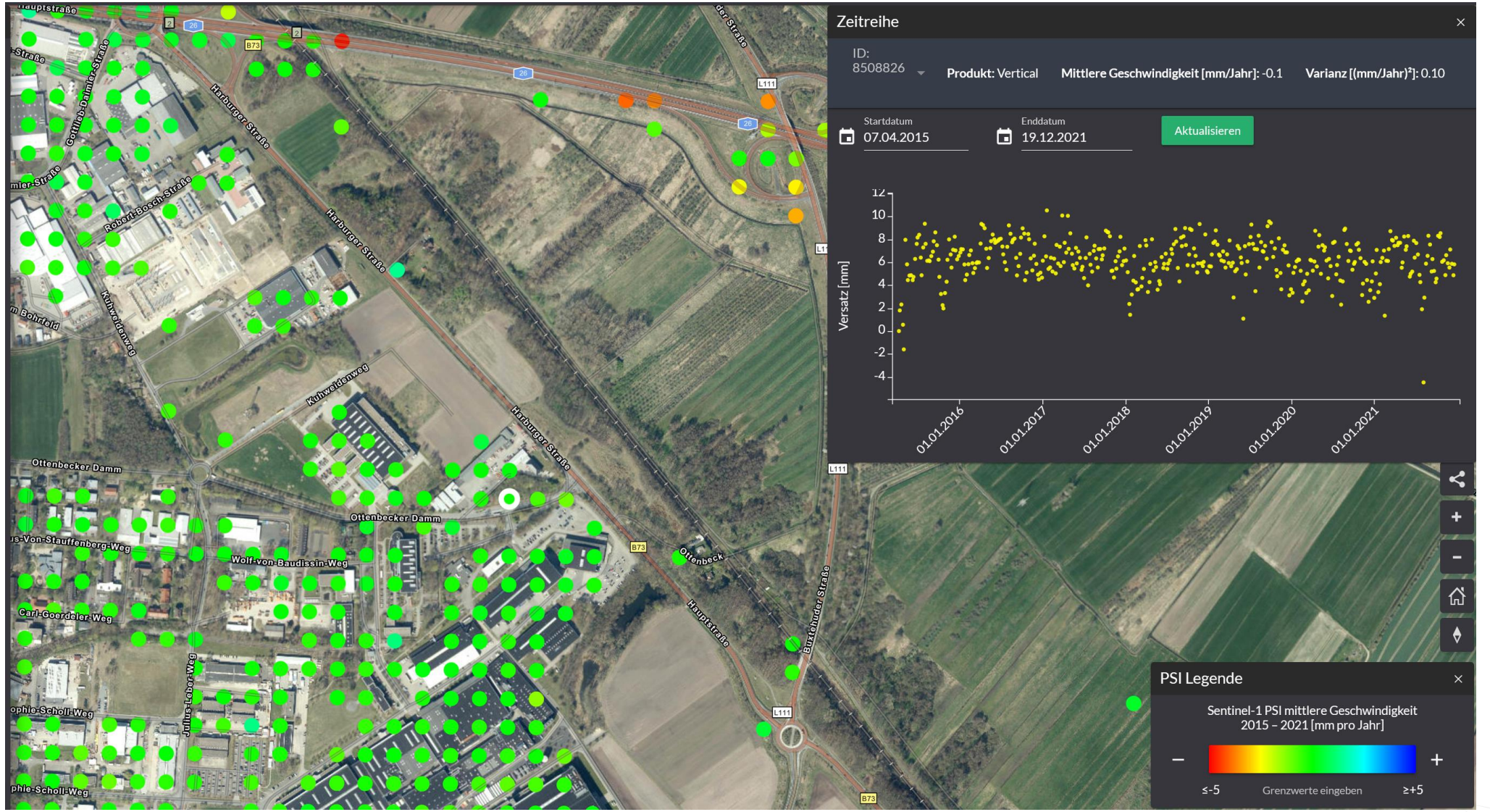
Surface subsidence



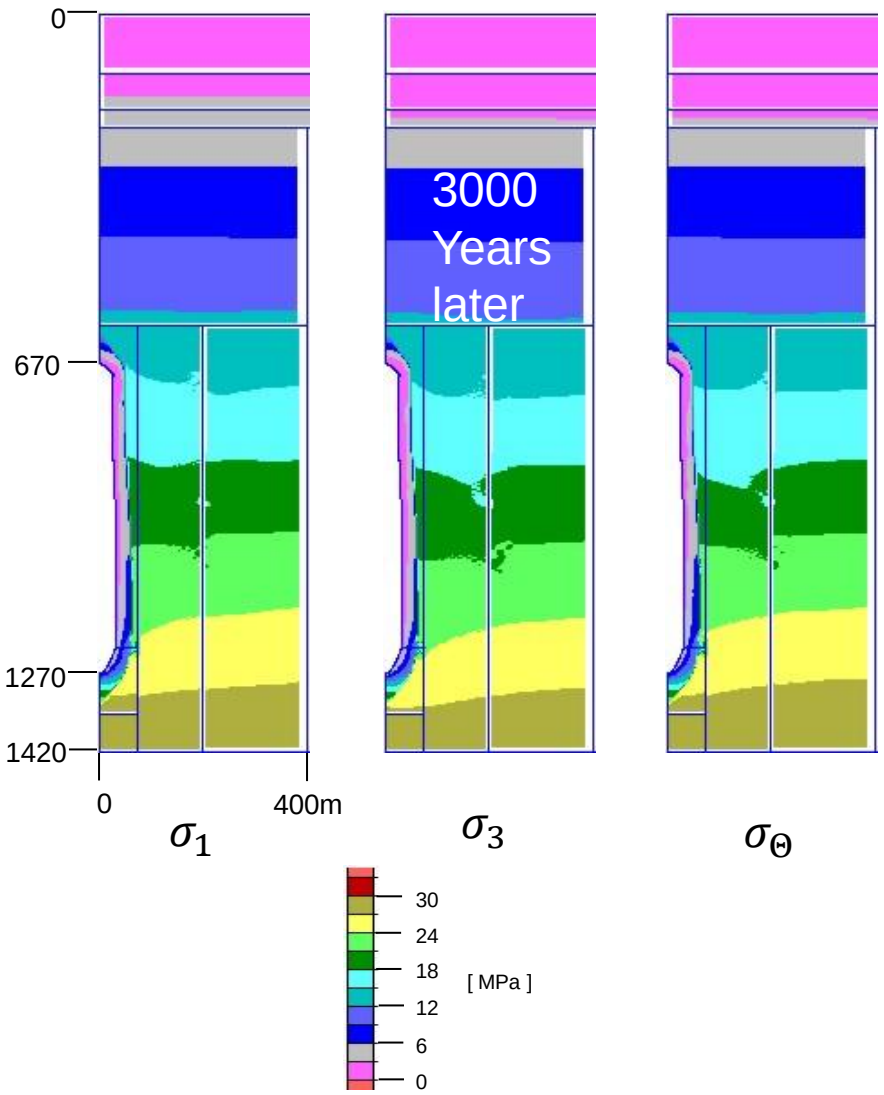
Brine permeation

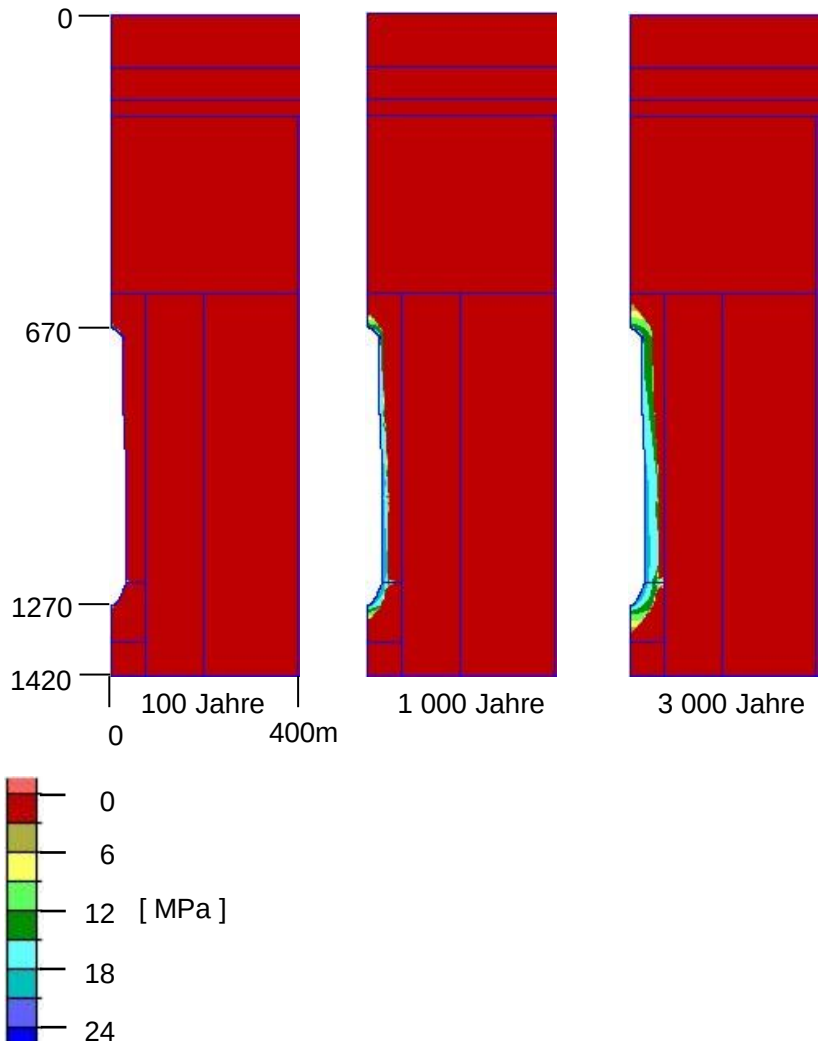


Subsidence at present



Prognosis of permeation





Model layout: field scale 3D model with detailed caverns

Triaxial Strength: $(\sigma_{vM})_{max} = \sigma_D + \frac{\sigma_{MAX} - \sigma_D}{\sigma_3 + \sigma_\phi} \cdot \sigma_3$

Strength depends on damage evolution

Creep modelling: $\dot{\varepsilon}_C = A_1 \cdot \exp\left(-\frac{Q_1}{R \cdot T}\right) \cdot \sigma^{n_1} + A_1 \cdot \exp\left(-\frac{Q_2}{R \cdot T}\right) \cdot \sigma^{n_1}$

multi component power law

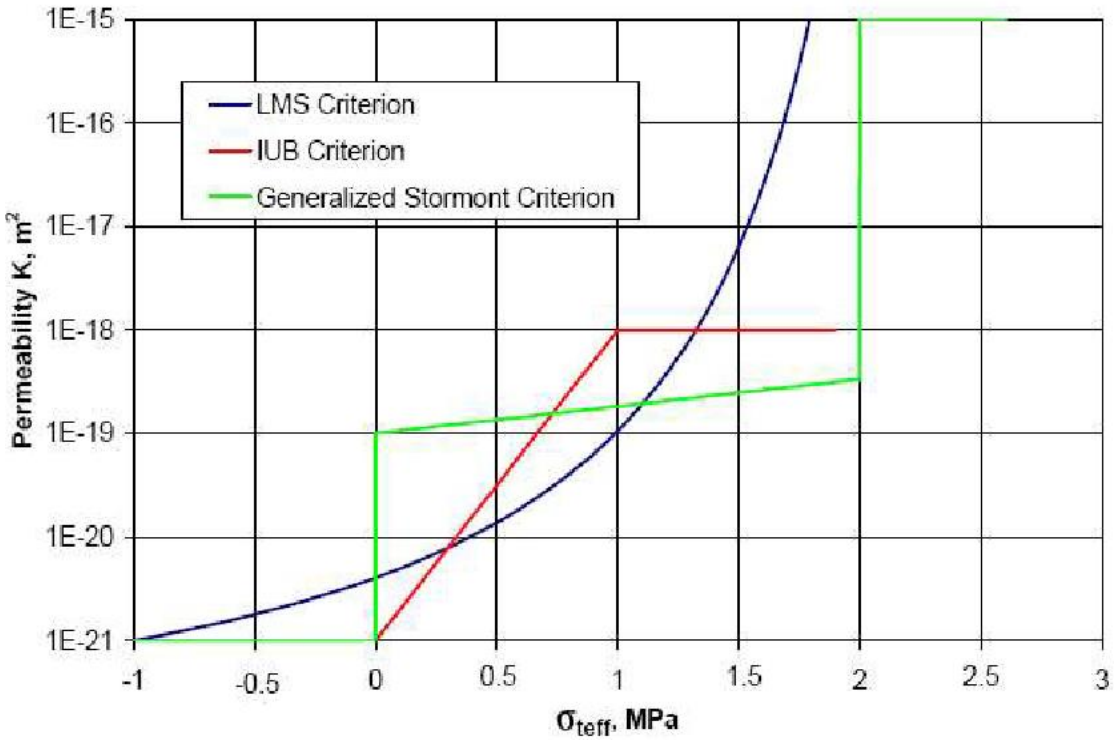
transient creep

Darcy flow approximation: $\frac{\Delta V}{\Delta t} = \frac{K(\sigma, p)}{\eta} \frac{A_E}{I_E} \Delta p$

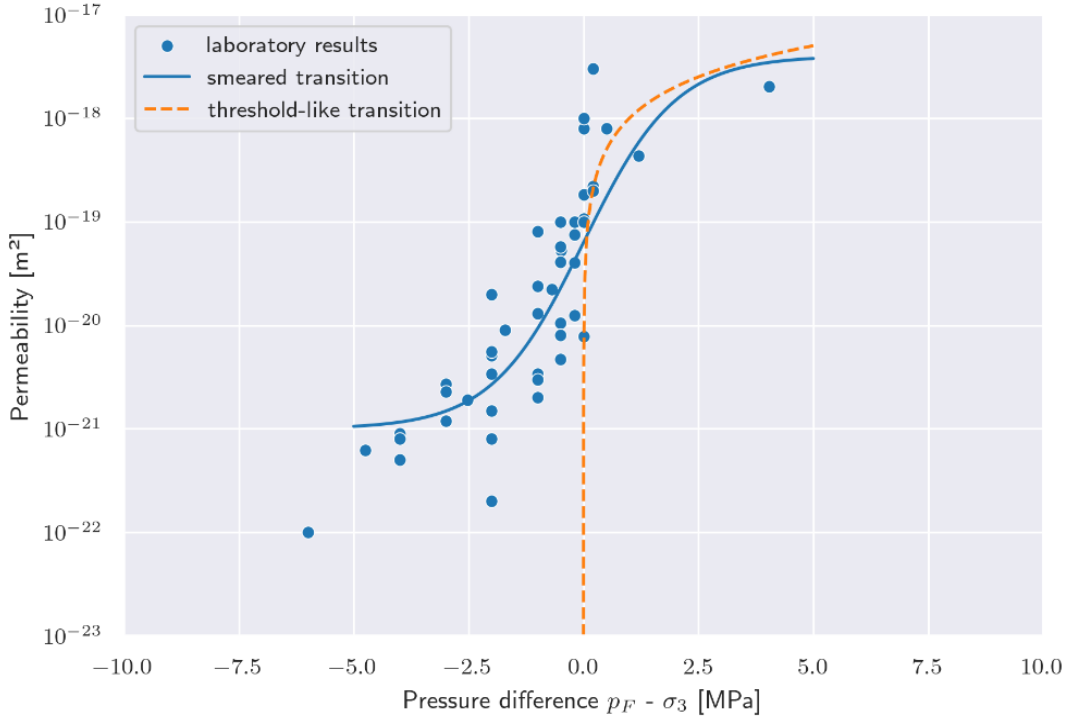
Stress- and pressure dependent permeability

Thermal effects included

[d⁻¹]

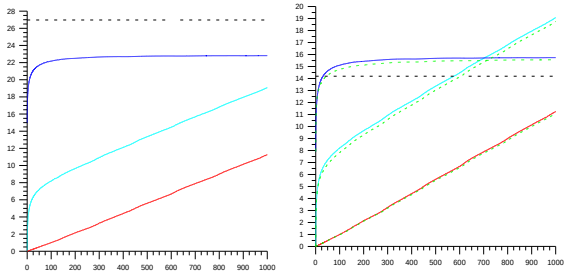


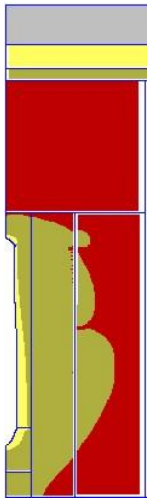
Different published permeability relations for the increase in permeability of rock salt when fluid pressure exceeds the least compressive stress component (Duquesnoy, 2017).



Laboratory results of hydro-mechanically coupled permeability measurements performed at the IfG for different fluid pressures in relation to the minor principal stress

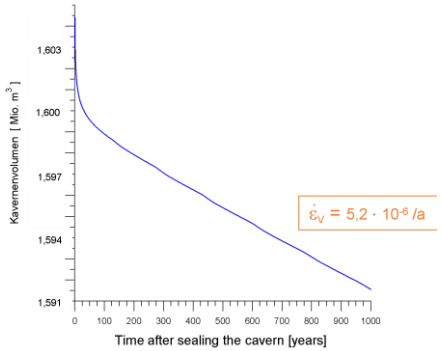
Sealing of caverns → pressure buildup due to convergence

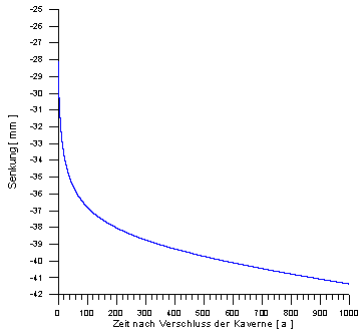


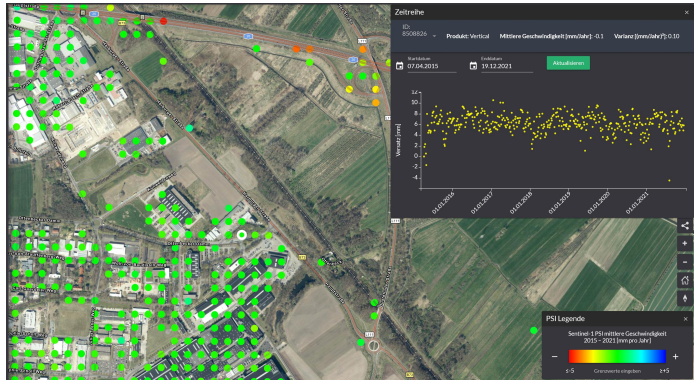


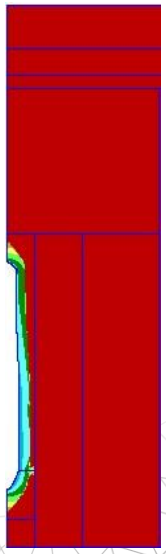
Brine pressure stabilizes cavern contour

Brine pressure reduced convergence and subsidence









Brine permeation into the salt only around contour

Thank you for your attention!