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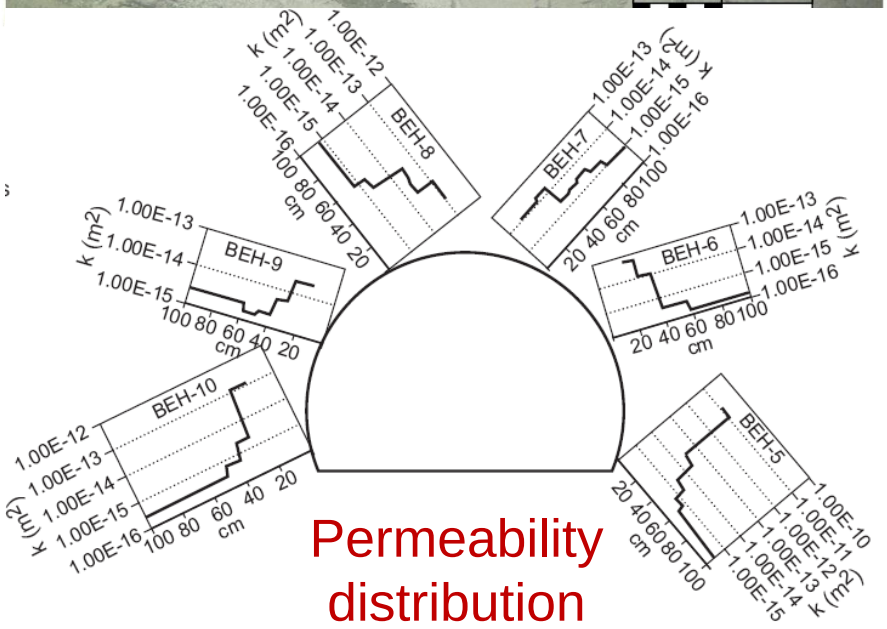
GRS Repository Safety Research Division, Germany

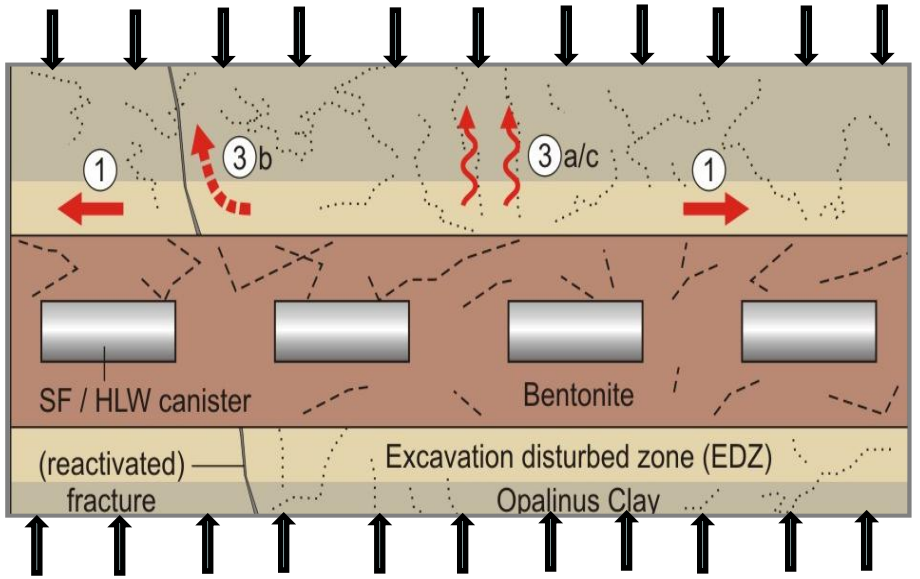
Self-Sealing of Fractures in Clay Rock for Disposal of Radioactive Waste

Excavation Damaged Zone



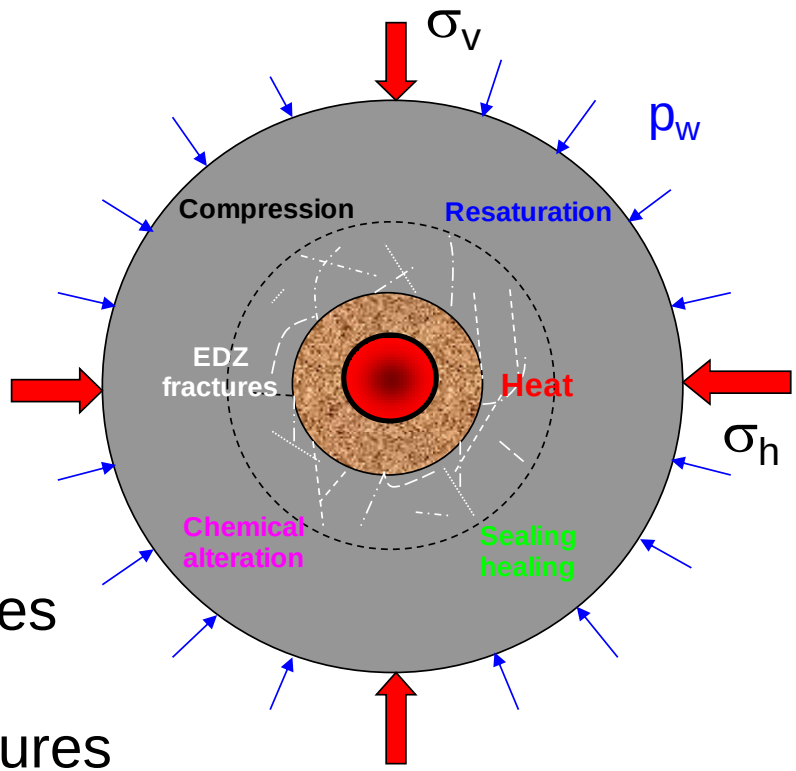
Permeability distribution

Sealing of EDZ expected



- Rock rheological compression & backfill withstand
- Swelling of claystone in EDZ by water uptake

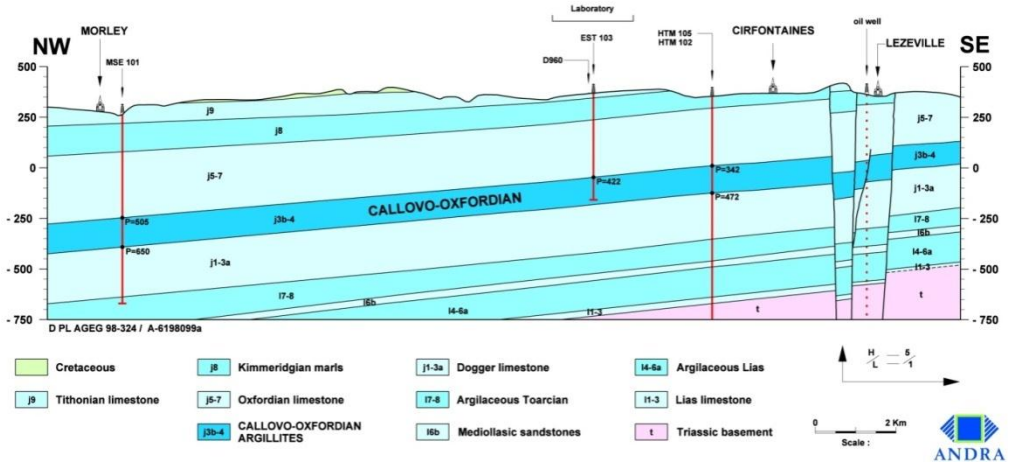
Experimental Evidence for Sealing of Fractures



1. Rock mechanical compression
2. Water-enhanced sealing of fractures
3. Thermal impact on sealing of fractures
4. Simulation of EDZ evolution around boreholes

Clay Rocks investigated at GRS Laboratory

Callovo-Oxfordian Argillite at the URL Bure

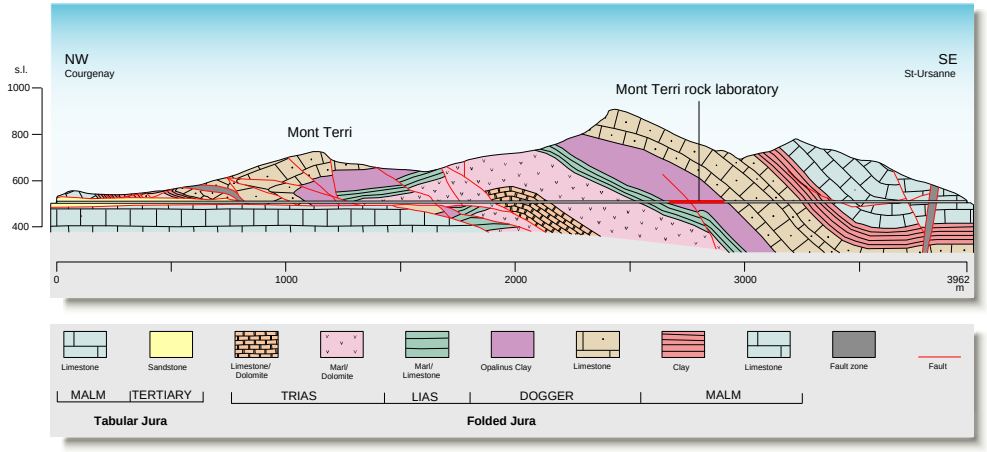


D28cm, L52cm

Basic characters

clay content	~42 %
water content	7.7 %
porosity	13~17 %
permeability	< 10^{-20} m^2
uniaxial strength	20~30 MPa

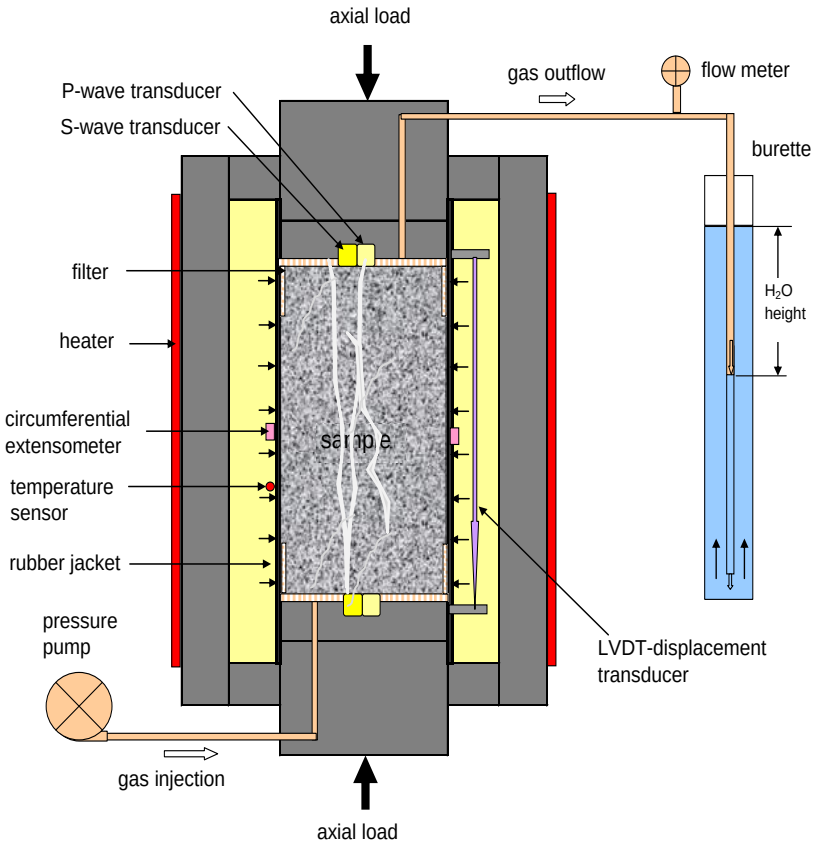
Opalinus Clay at the URL Mont Terri



D28cm, L70cm

clay content	~65 %
water content	6.7 %
porosity	14~17 %
permeability	< 10^{-20} m^2
uniaxial strength	10~15 MPa

1. Sealing of fractures under mechanical compression

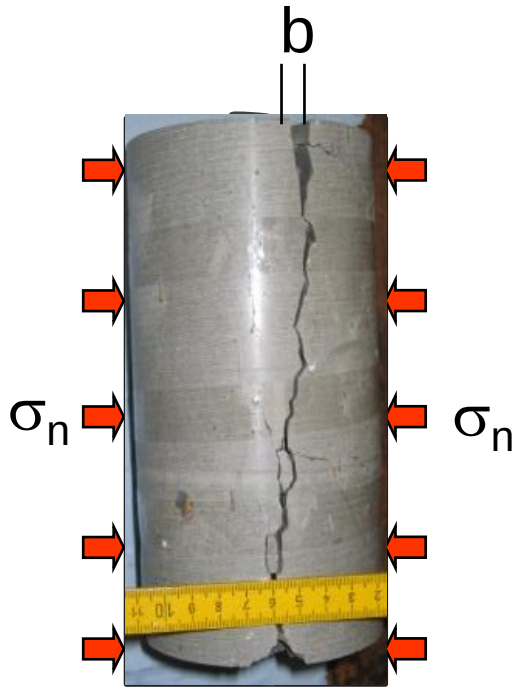


COX sample

OPA sample

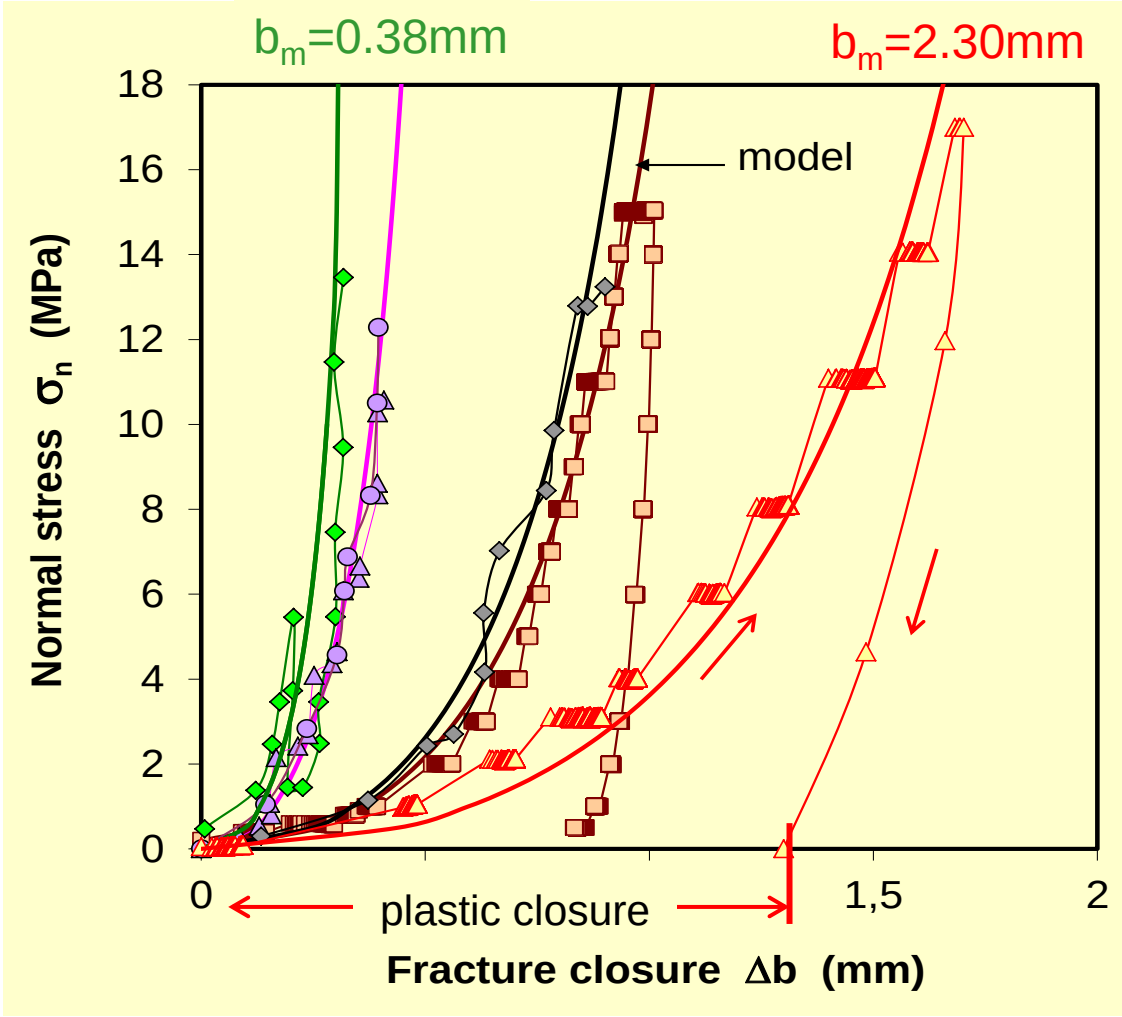
fracture closure
gas permeability

Fracture closure under normal stress

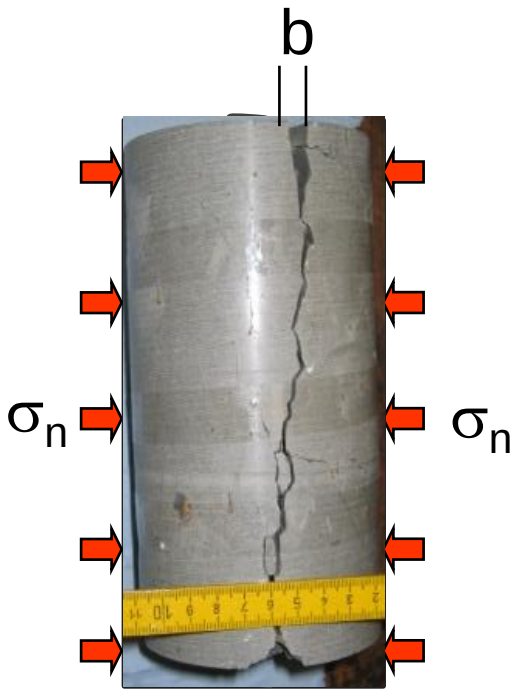


$$\Delta b = b_m \left[1 - \exp\left(-\alpha \sigma_n^{\ \beta}\right)\right]$$

$$\sigma_n \rightarrow \infty \Longrightarrow \quad b \rightarrow 0$$

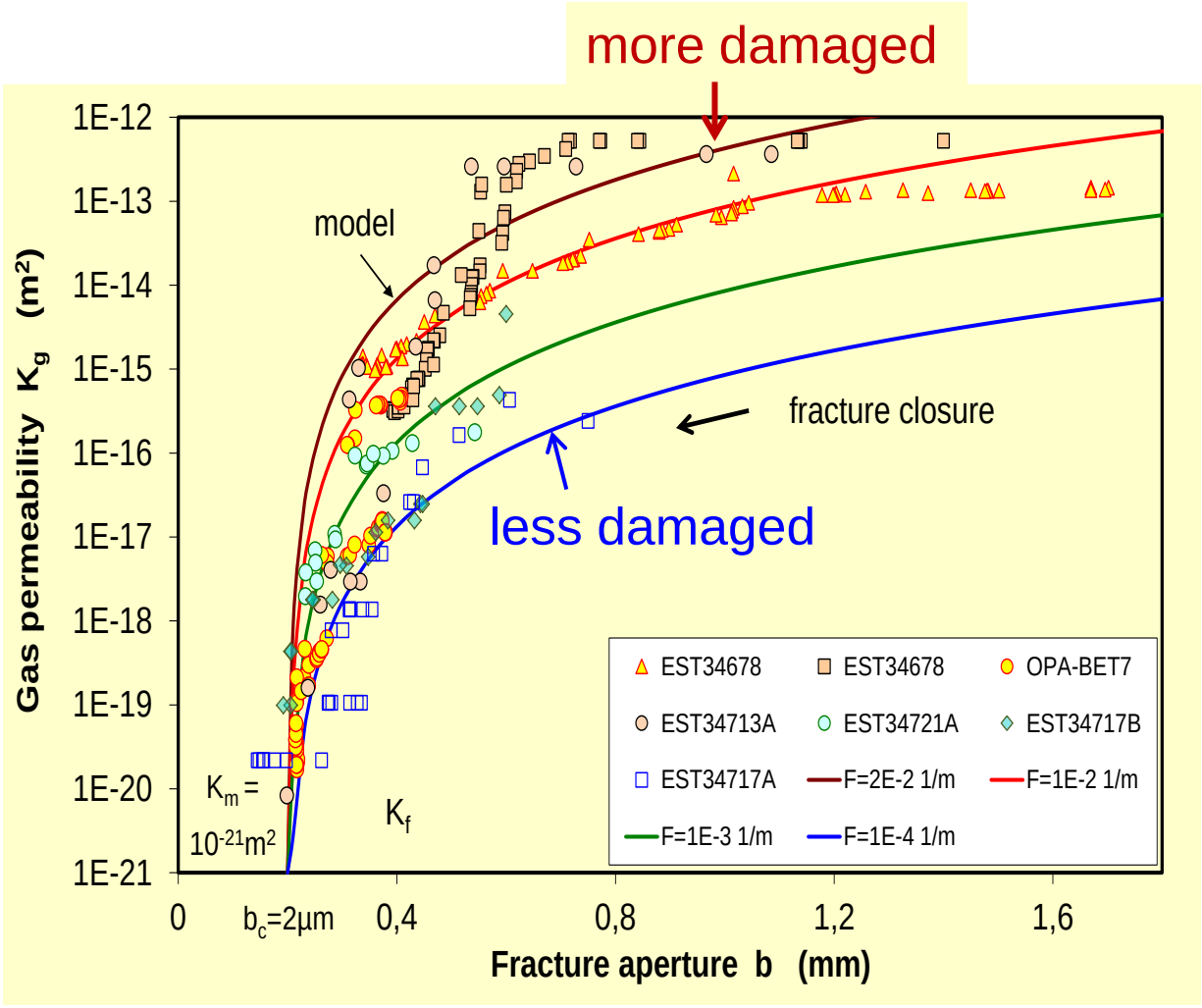


Fracture closure and permeability decrease

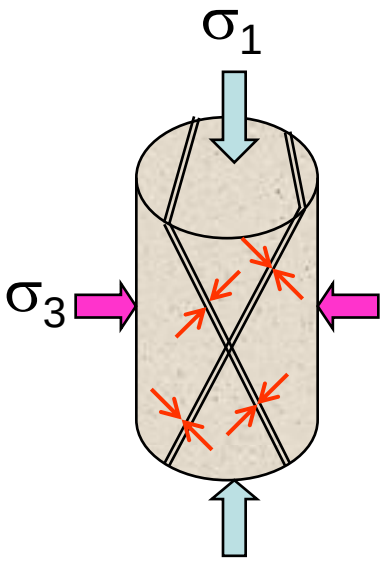


$$K = K_m + \frac{R(b - b_c)^3}{12s}$$

$$b \to b_c \Longrightarrow K \to K_m < 10^{-20}\ m^2$$



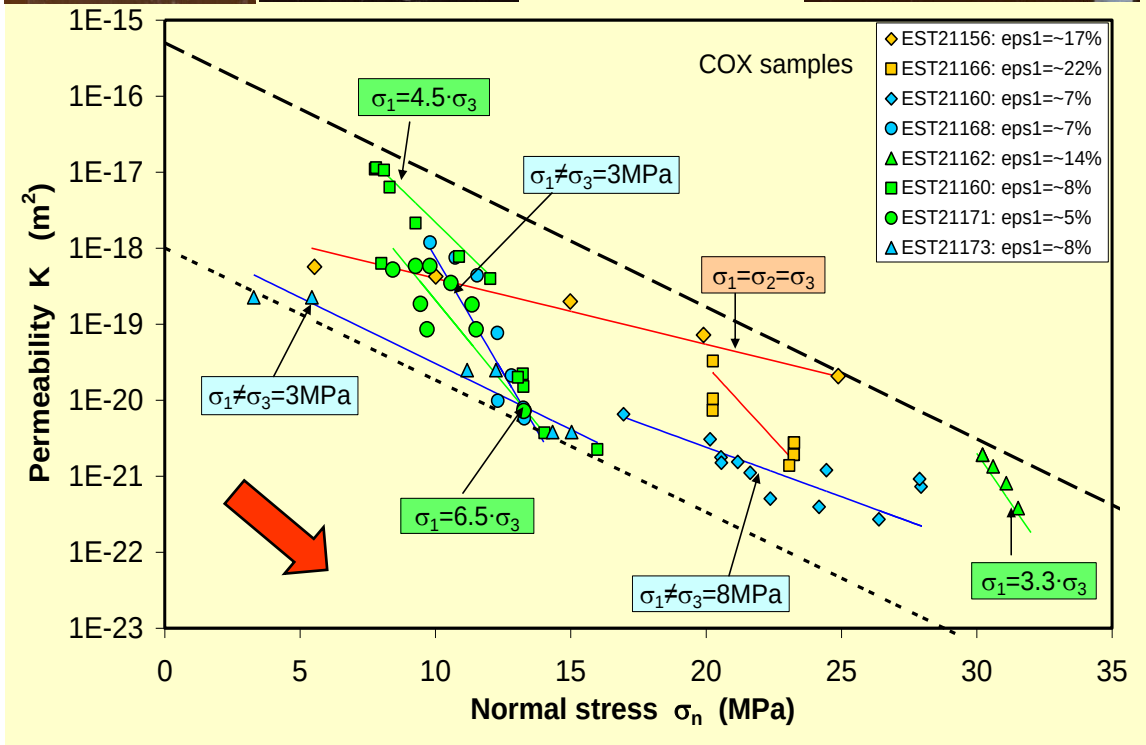
Sealing of shear fractures by compression



$\sigma_1 = \sigma_2 = \sigma_3$ ⇑

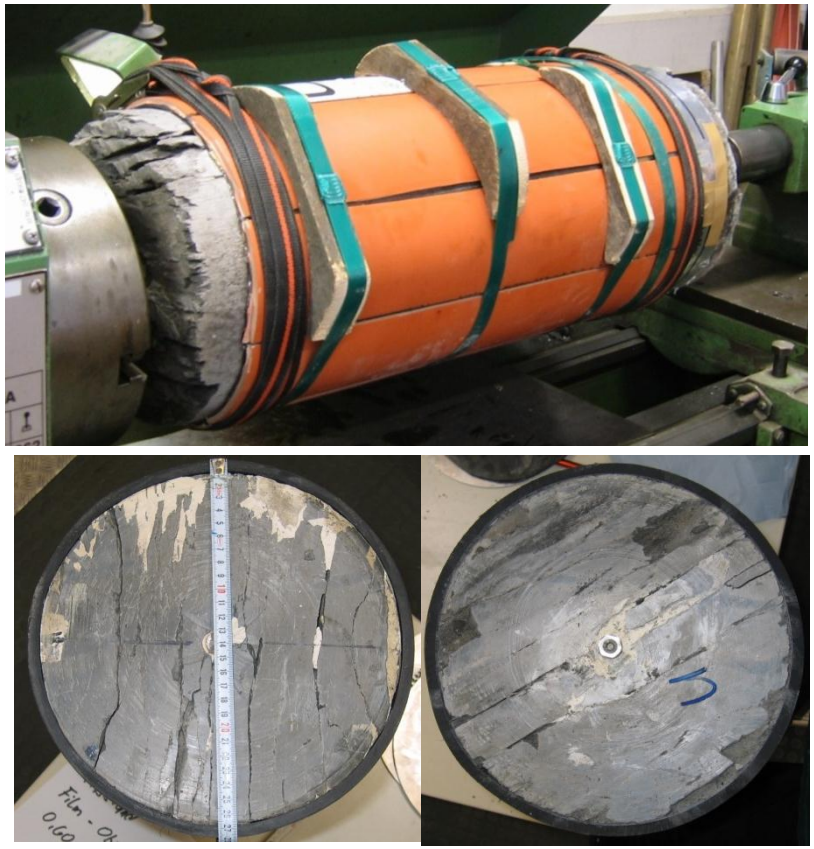
$\sigma_1 = a \cdot \sigma_3$ ⇑

$\sigma_3 = c, \quad \sigma_1$ ⇑



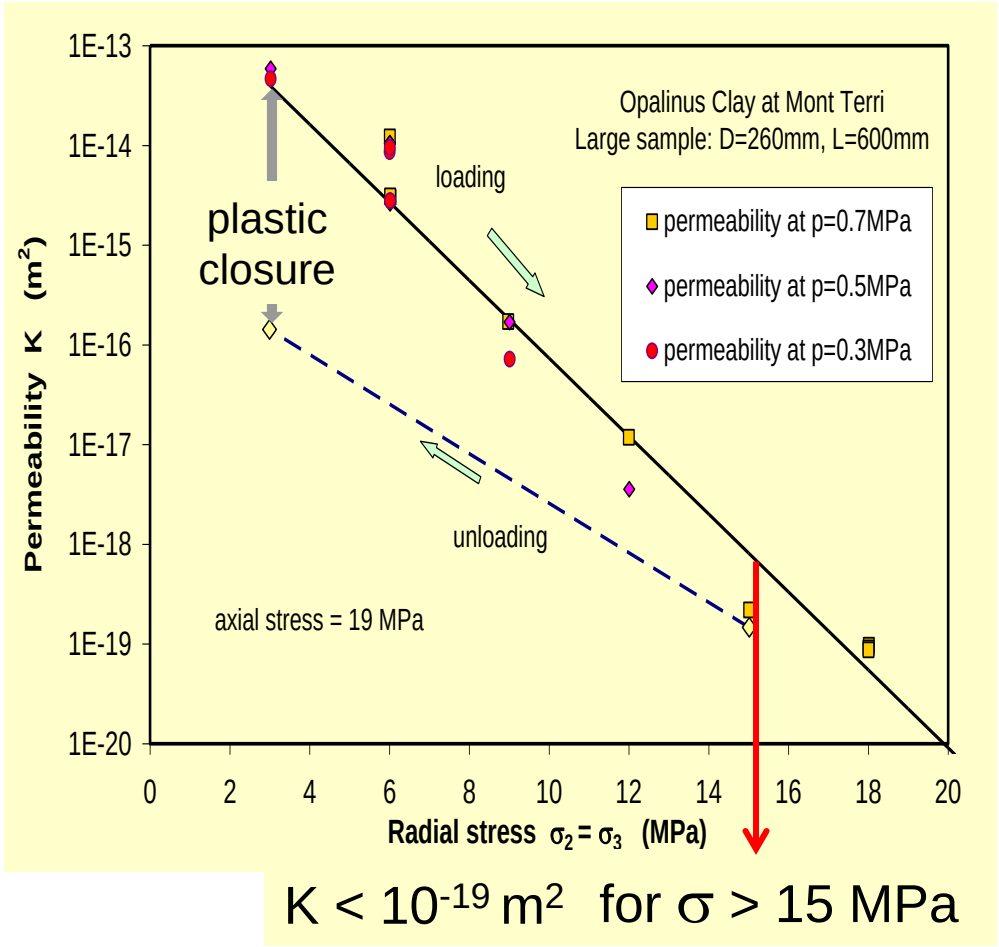
Sealing of fractures in large-scale samples

OPA sample (D260mm, L600mm)



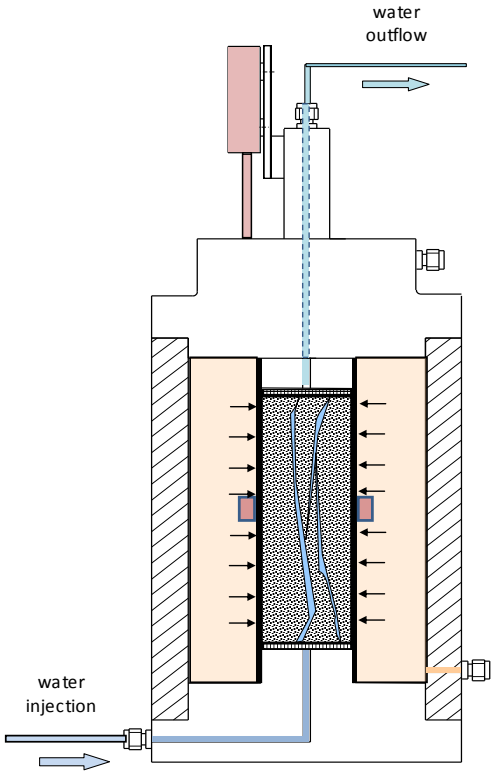
Fractures parallel to sample axis

Permeability – confining stress



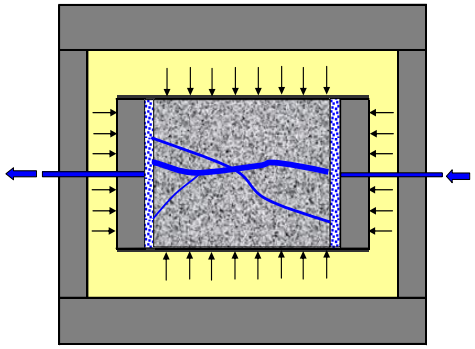
$K < 10^{-19}\ m^2$ for $\sigma > 15$ MPa

2. Water-enhanced sealing of fractures

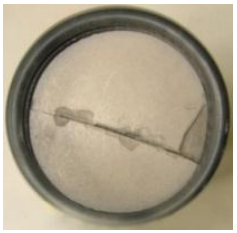


triaxial cell
fracture closure
water permeability

synthetic porewater flow



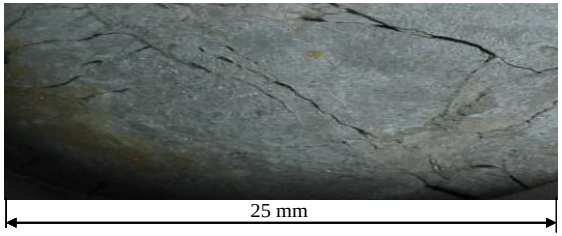
permeameters
long-term water permeability

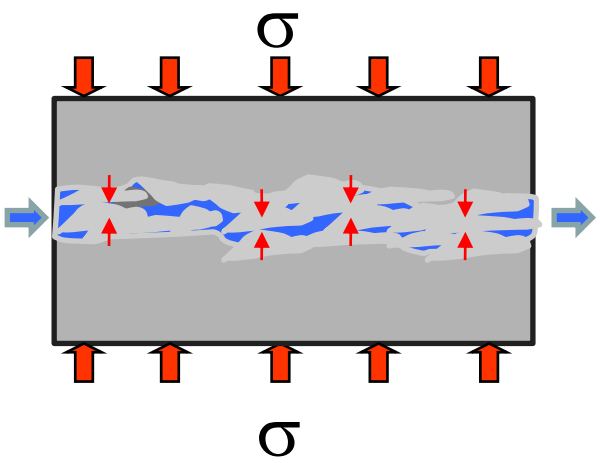


fractured samples

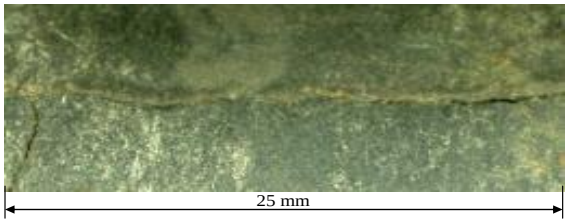
Fracture closure and water permeability

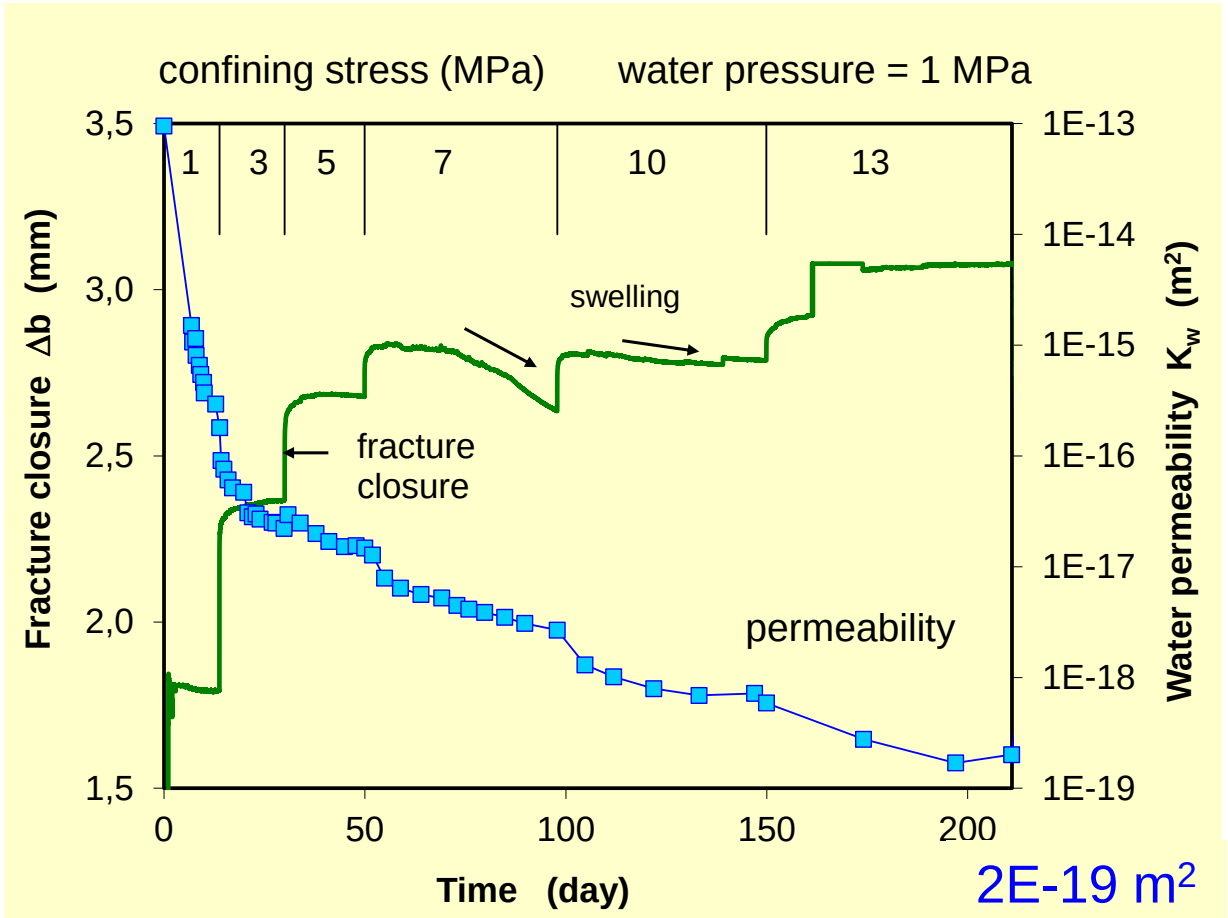
before test





after test

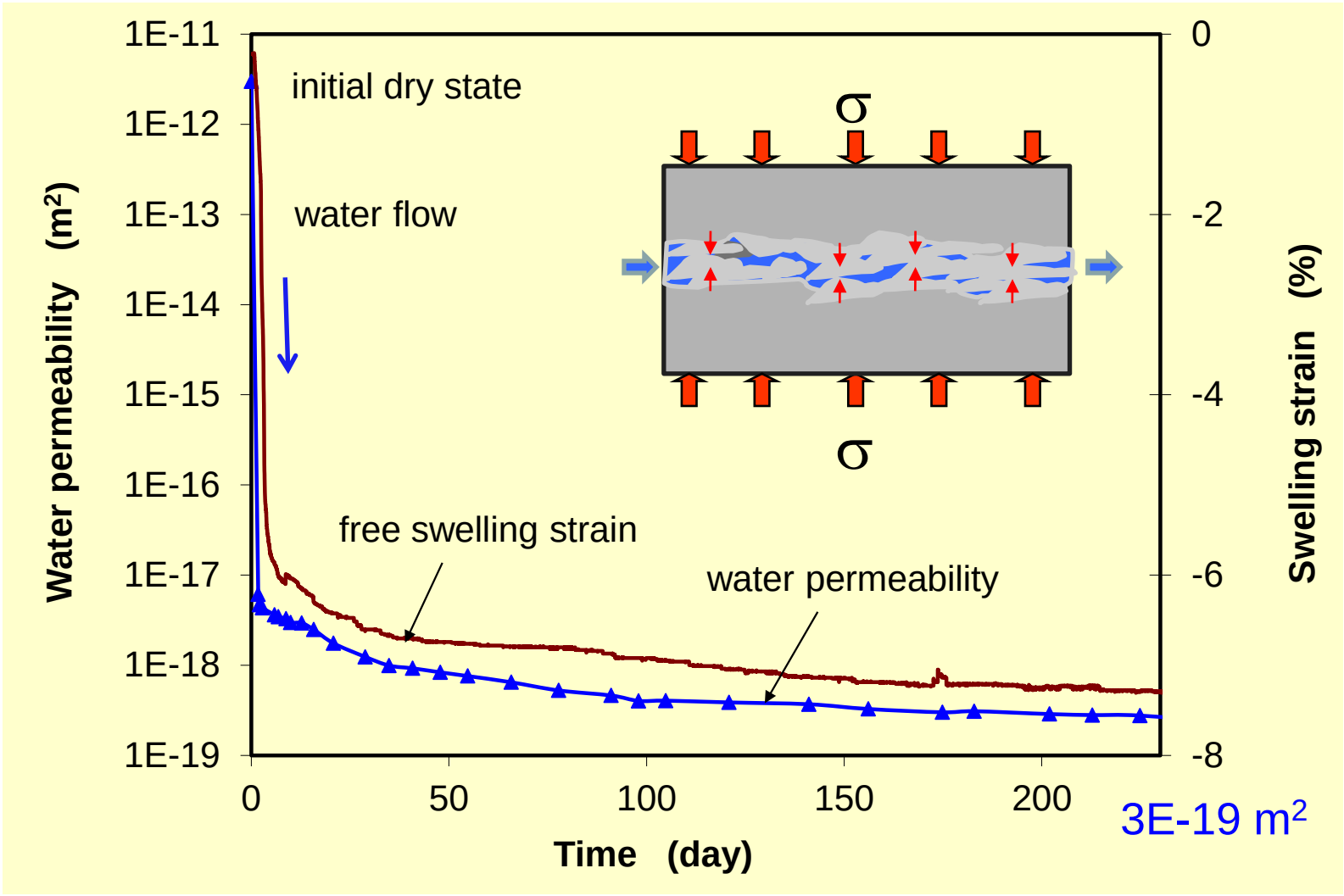




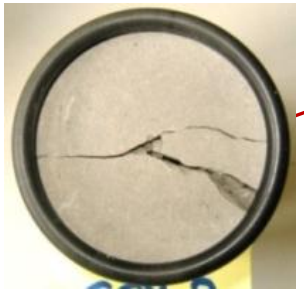
2E-19 m^2

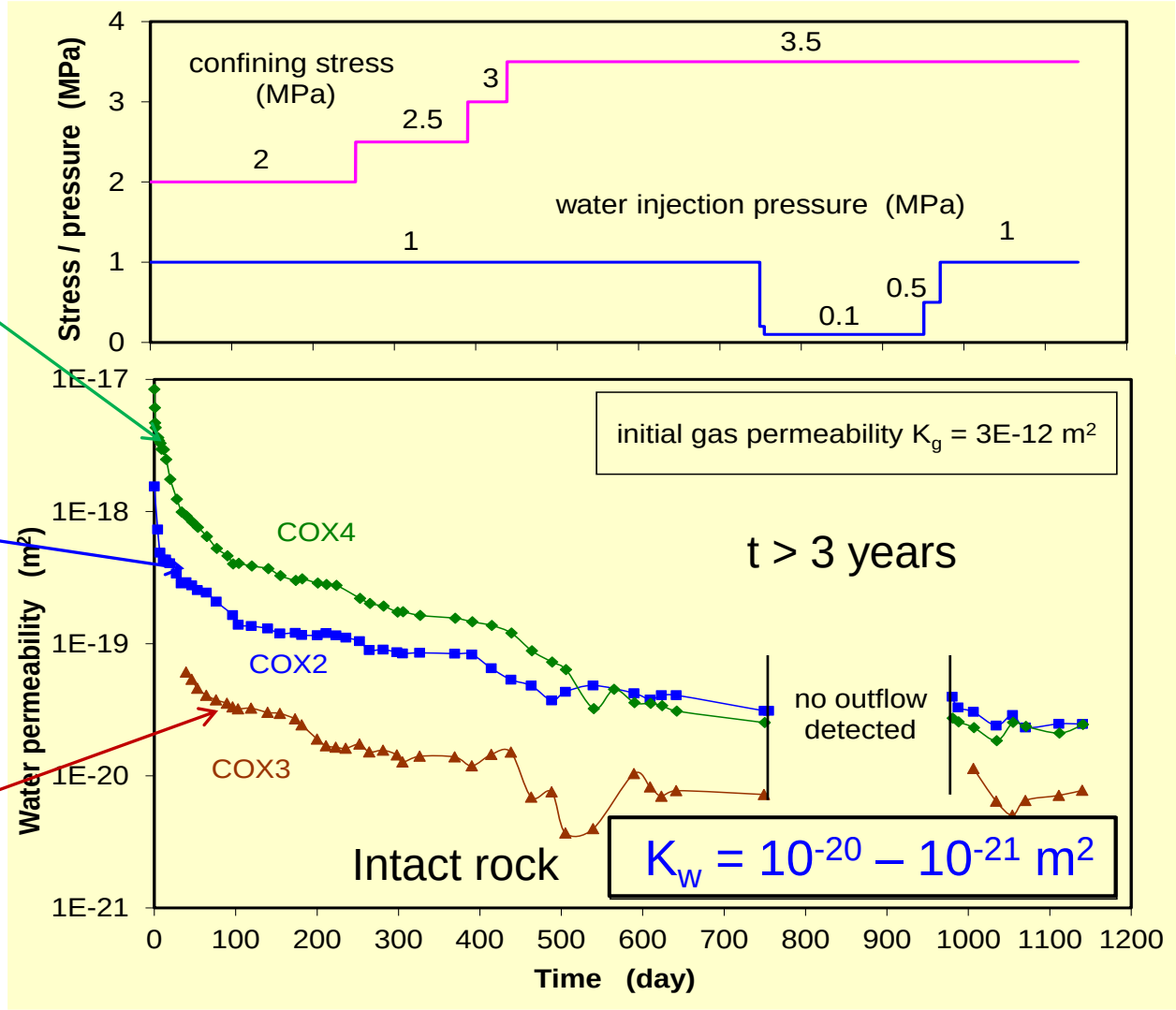
compaction; swelling; slaking; clogging

Water permeability related to clay swelling

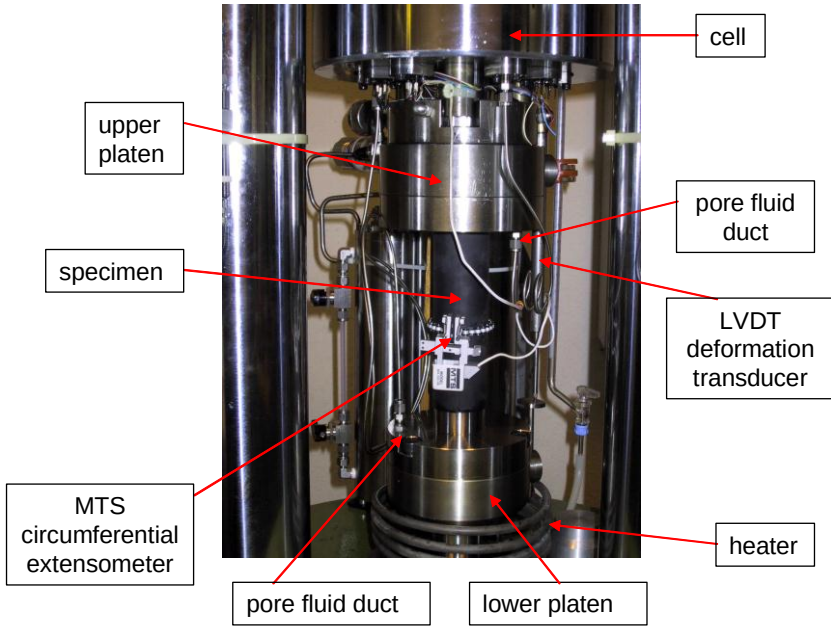


Long-term water permeability of fractured claystone

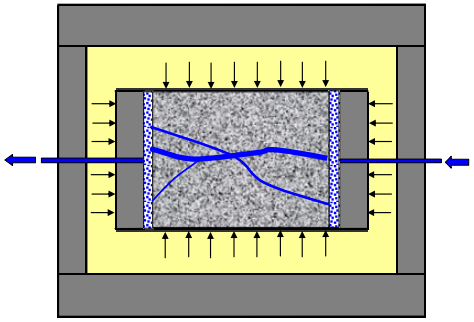


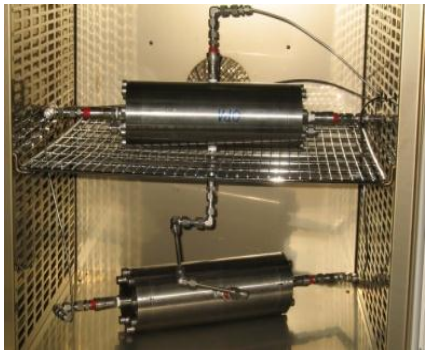


3. Thermal impact on sealing of fractures

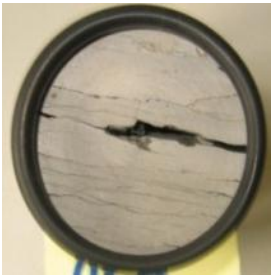


heating in a triaxial cell
fracture closure
water permeability





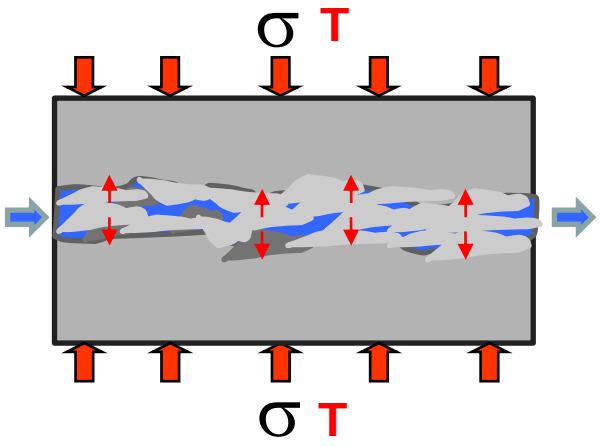
heating in an oven
long-term water permeability



OPA sample

COX sample

Thermal impact on fracture closure and permeability



Coupled effects:

Mechanical compression

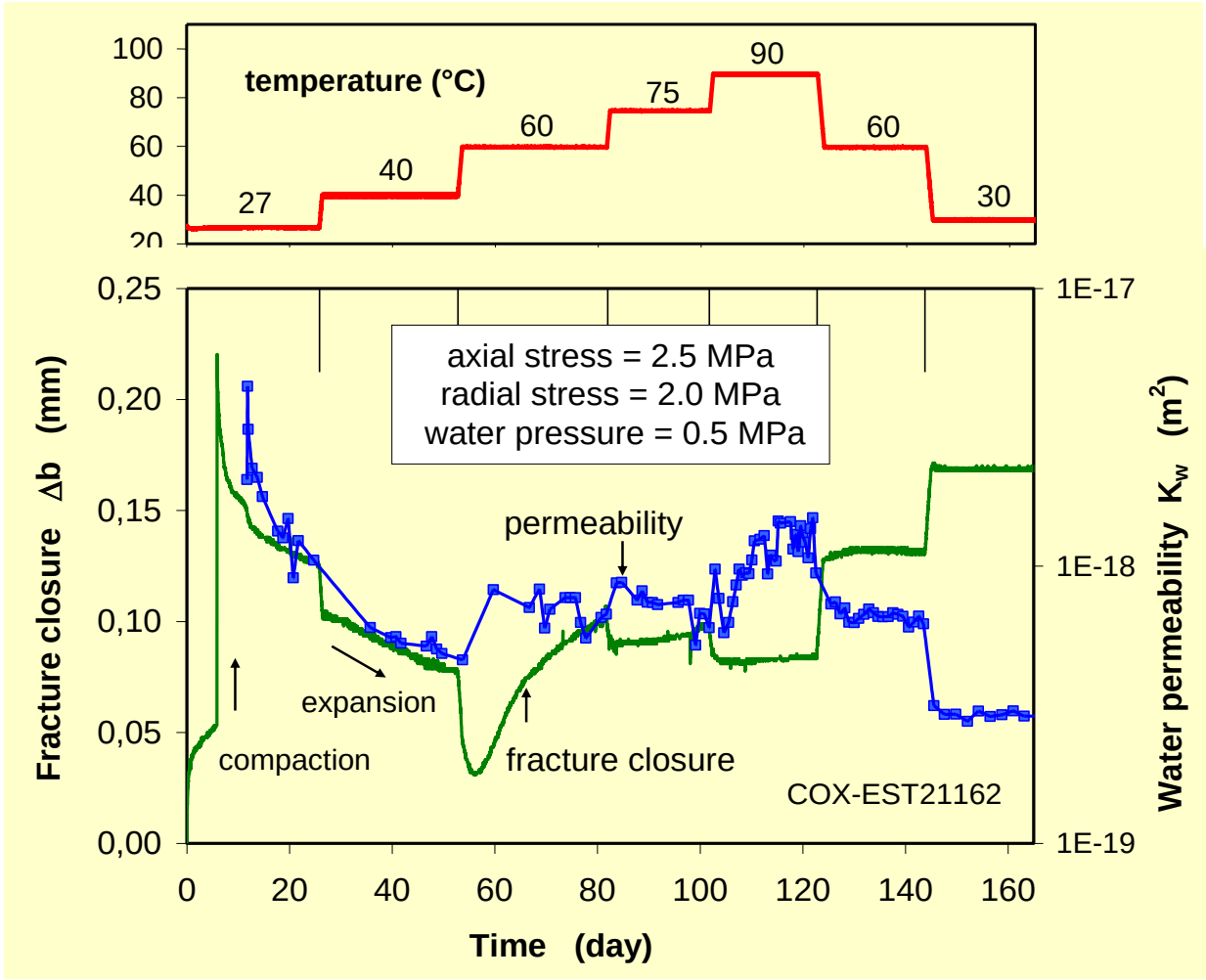
Water-enhanced

swelling/sealing

viscosity change

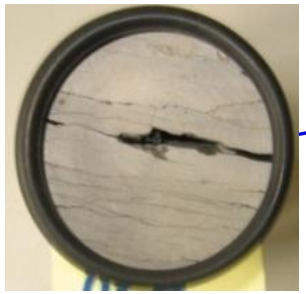
Thermal-induced

fracture opening/closing

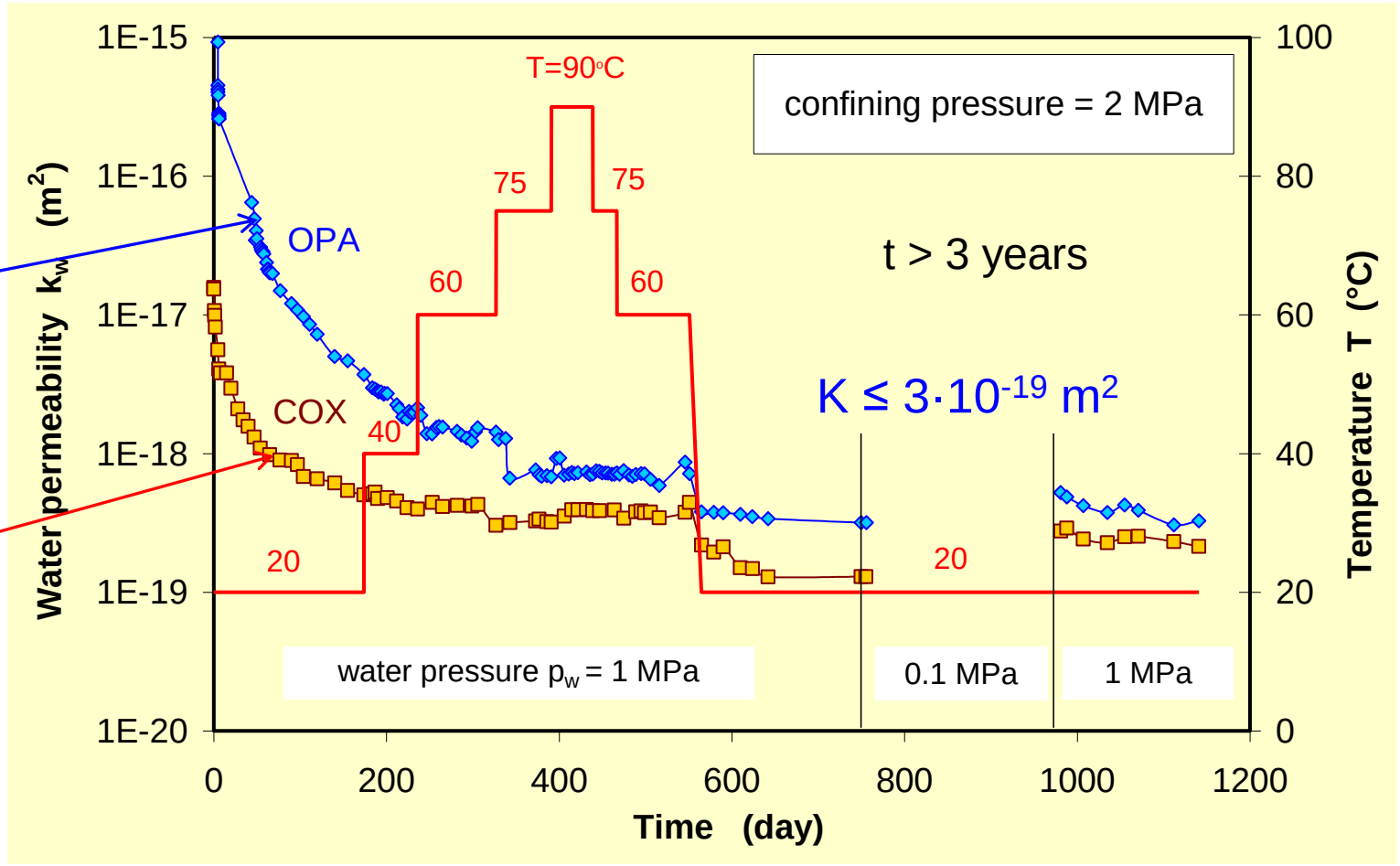


Long-term permeability during heating/cooling cycle

OPA

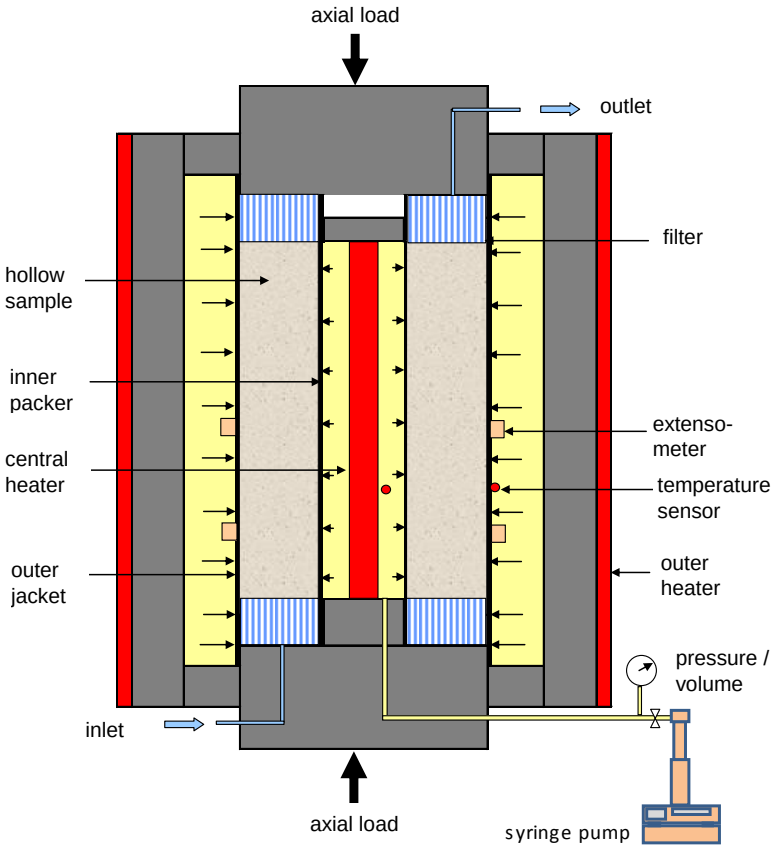


COX



4. Simulation of EDZ-evolution around boreholes

D/L/d=280/500/100mm

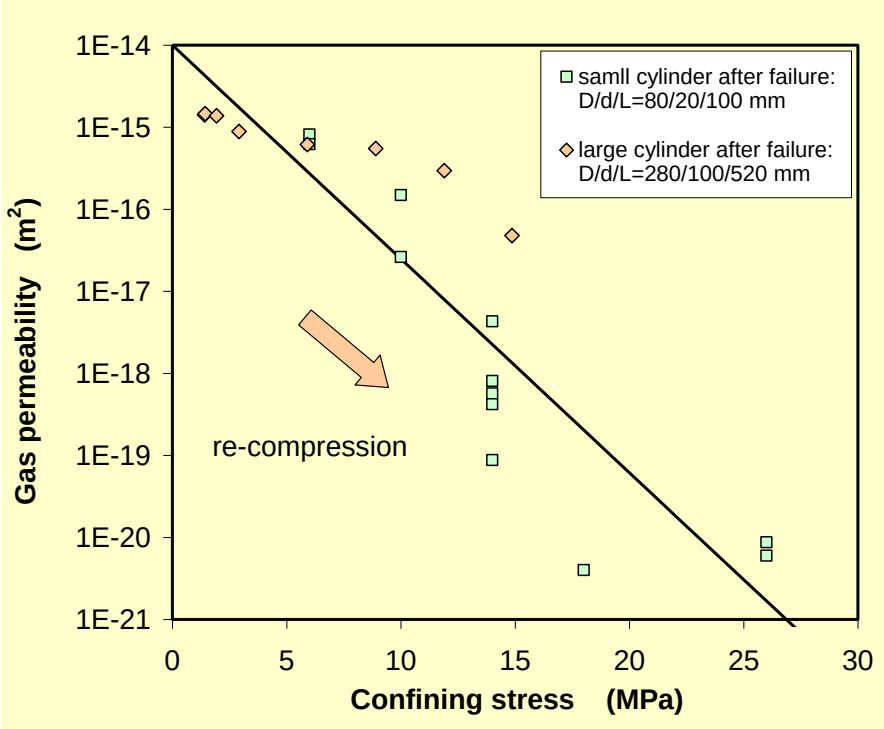


before testing

after damage

Sealing of EDZ around a borehole

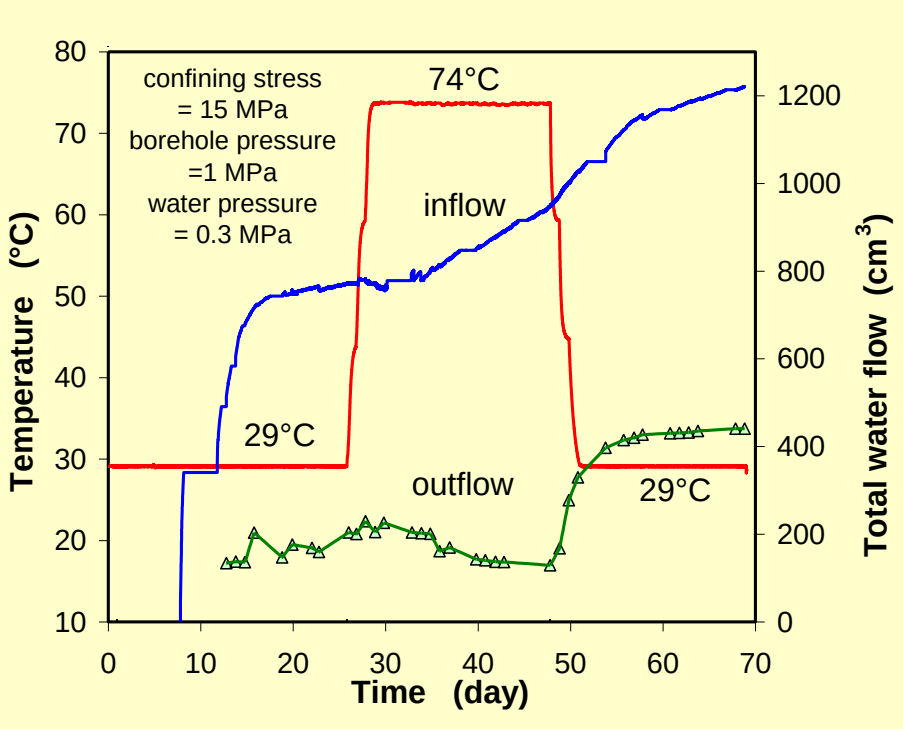
gas flow by re-compaction



$K < 10^{-19}\ m^2$

for $\sigma > 15$ MPa

water flow at thermal load



before heating: $K = 2 \cdot 10^{-18}\ m^2$

after heating: $K = 3 \cdot 10^{-18}\ m^2$

Conclusions

- Strong experimental evidence for the high sealing capability of the studied clay rocks
- Fracture closure and permeability decrease significantly with confining stress
- Water flow enhances the sealing of fractures dramatically
- Thermal impact on the sealing of fractures insignificant
- Fractures in clay rocks can be fully re-sealed to the intact state under the repository conditions
- Models needed for prediction and assessment of the realistic sealing process of the EDZ in repositories

Acknowledgements

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- The support from **ANDRA** by providing the samples

Thank you for your attention !