
Development, testing, and numerical simulation of shaft sealing elements made of bitumen and asphalt for German HLW and SF repository

*Philipp Herold¹, Michael Jobmann¹, Eric Kuate Simo¹, Christian Müller¹,
Matthias Gruner², Martin Hofmann², Wolfram Kudla²*

¹ – DBE TECHNOLOGY GmbH

² – TU Bergakademie Freiberg

Clay Conference 2017

Davos, Switzerland

September 24 - 27, 2017

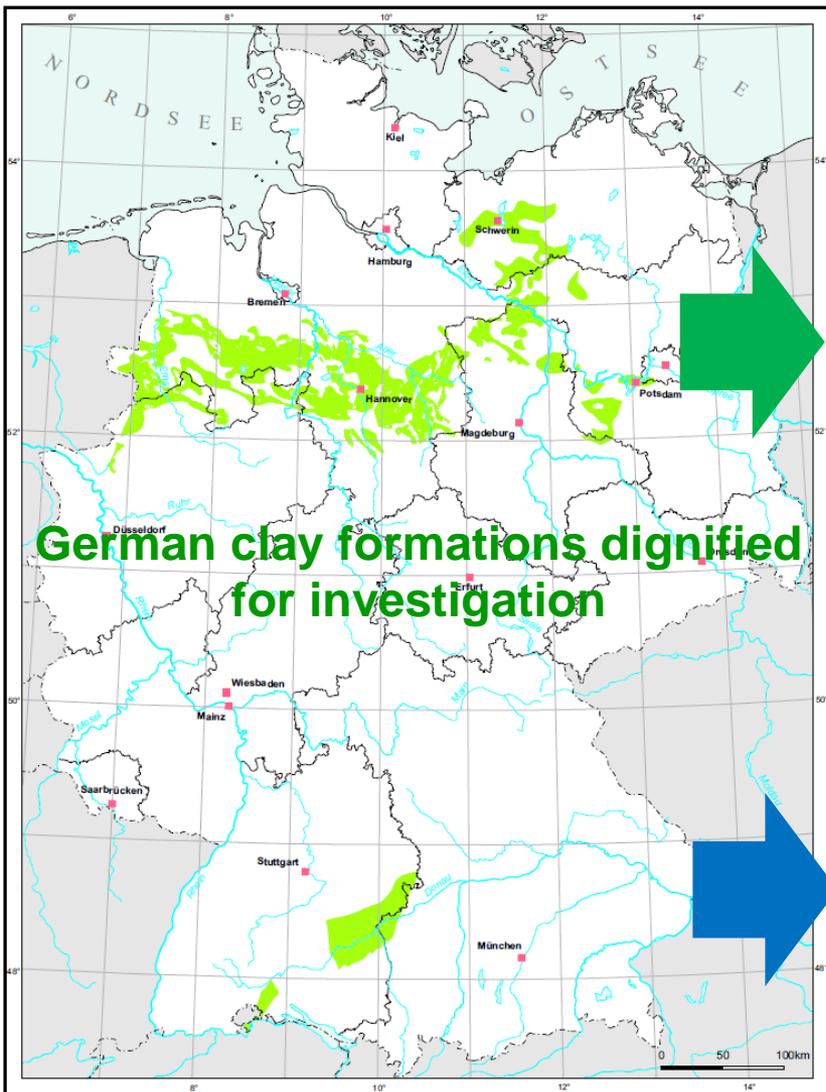
Contents

- (1) Final disposal in Germany
- (2) Shaft sealing concepts in combination with bitumen and asphalt
- (3) Shaft sealing elements made of asphalt and bitumen
- (4) Material behavior of asphalt and bitumen
- (5) Thermo-mechanical effects during installation

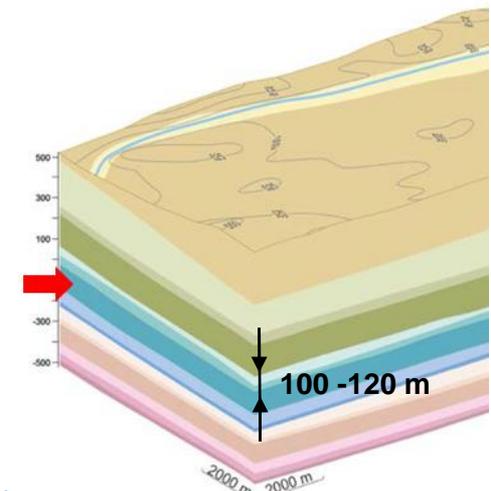
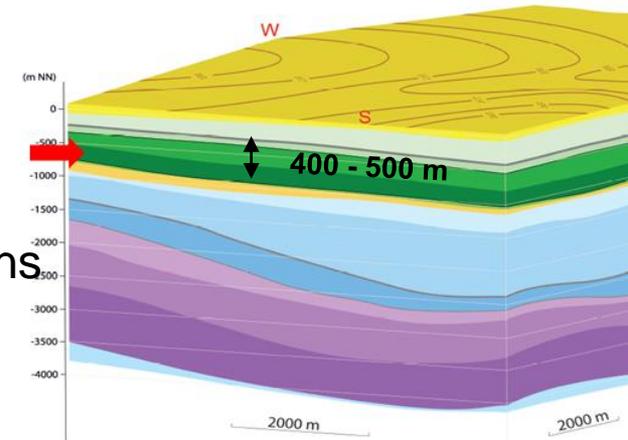
Final Disposal in Germany

- Disposal in deep rock salt formations was the preferred option in the last decades
- Restart of the site selection process for a SF/HLW repository by law (2013)
- Recommendations of the German Commission on the Storage of HLW:
 - Disposal of SF/HLW in deep geologic formations with the possibility of retrieving waste packages as a preferred option
 - Consider salt, clay, and crystalline rock as potential host rocks
 - Detailed course of action and geologic criteria for the new site selection process
 - Re-organization of responsible authorities
- Revised law with implemented recommendations passed German Parliament (Bundestag) and Federal Council (Bundesrat) in March 2017
- Major steps: selection of a new site by 2031 and start of operation in 2045/50

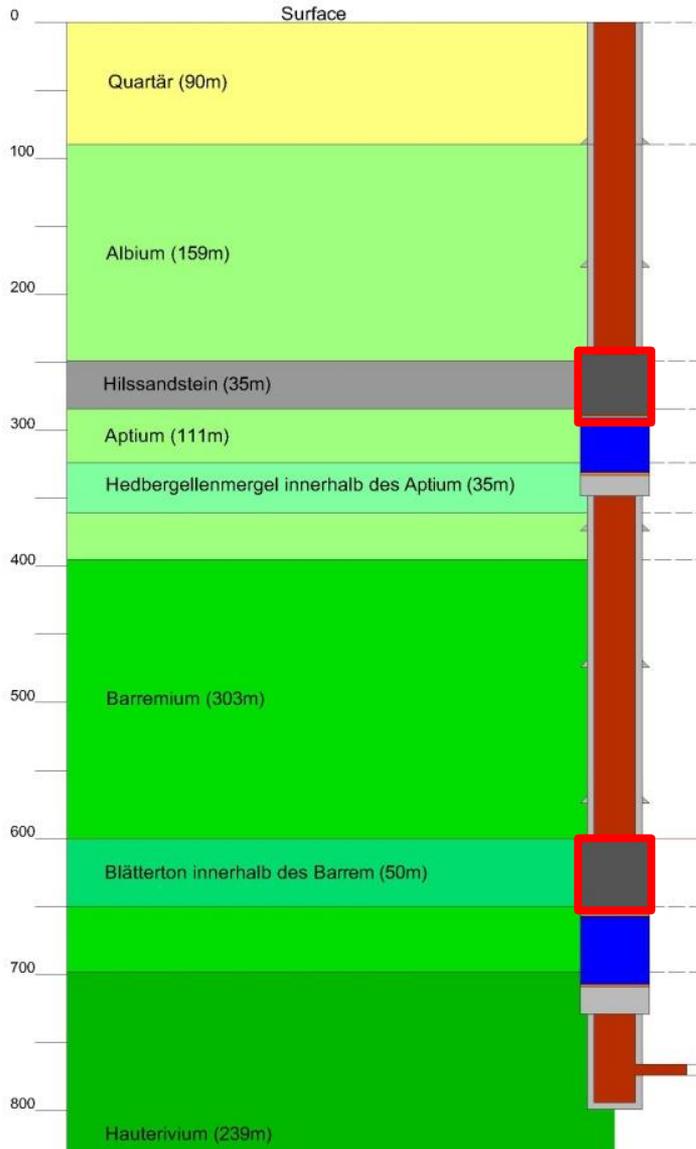
Reference models for German clay formations



- Huge Cretaceous clay formations in northern Germany
- Two main formations “Barremium” and “Hauterivium”
- Thinner but well-known Jurassic clay formation (Opalinus clay) in southern Germany
- Already being investigated as part of the Swiss disposal concept



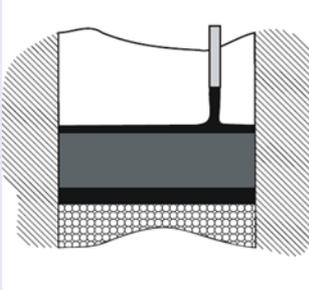
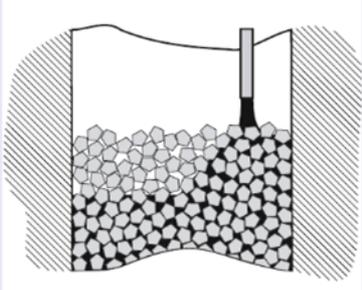
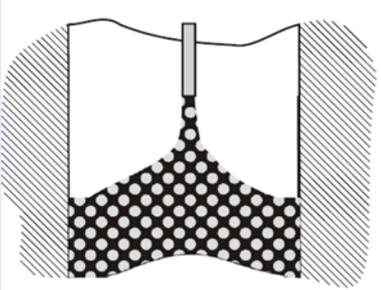
Shaft sealing concepts



Shaft sealing concept for Cretaceous clay formations as expected in northern Germany, developed within the ELSA project:

- Main seal made of bentonite within the host rock formation
- additional bentonite seal to separate aquifers
- bitumen/asphalt sealing elements support bentonite seal:
 - protect the bentonite against (to fast) water inflow from above
 - provide intermediate sealing function until the bentonite is saturated and provides full sealing function
 - close pores and cracks at the contour and EDZ

Types of sealing elements

System	Bitumen Sandwich	Bitumen-filled gravel column	Asphalt with rounded gravel
Function	Sealing	Sealing and Abutment	Sealing and Abutment
Design			
Materials	Bitumen with different viscosity	Crushed Basalt 32 / 63 mm Bitumen, standard or with filler	Rounded Basalt 20 / 40 mm Bitumen, standard or with filler
Related to	Konrad project	ERAM project	ELSA project
Status	<ul style="list-style-type: none"> • Conceptual design • small scale in-situ test within ELSA 	<ul style="list-style-type: none"> • Pilot tests at TU Bergakademie Freiberg Full-scale field test (BISETO Project, supported by BfS) • small scale in-situ test within ELSA 	<ul style="list-style-type: none"> • design and development • small scale in-situ test within ELSA

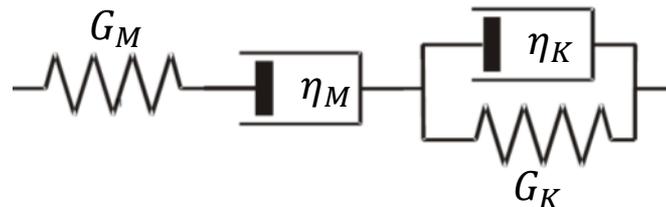
Bitumen and asphalt

Bitumen:

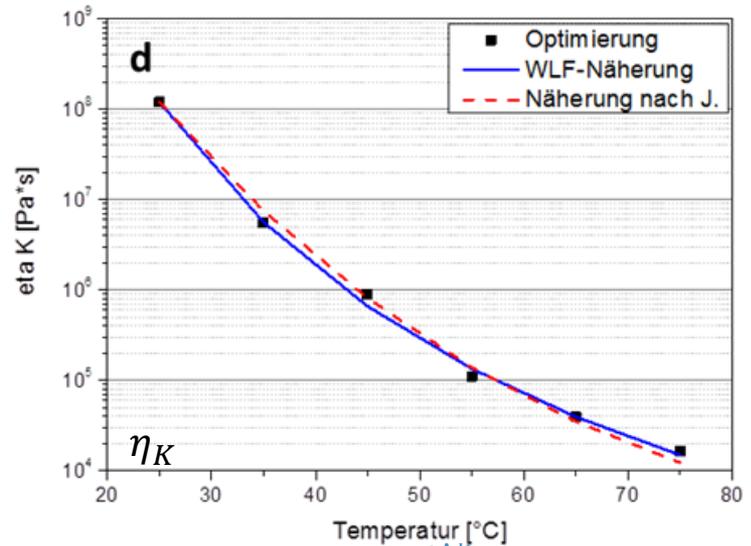
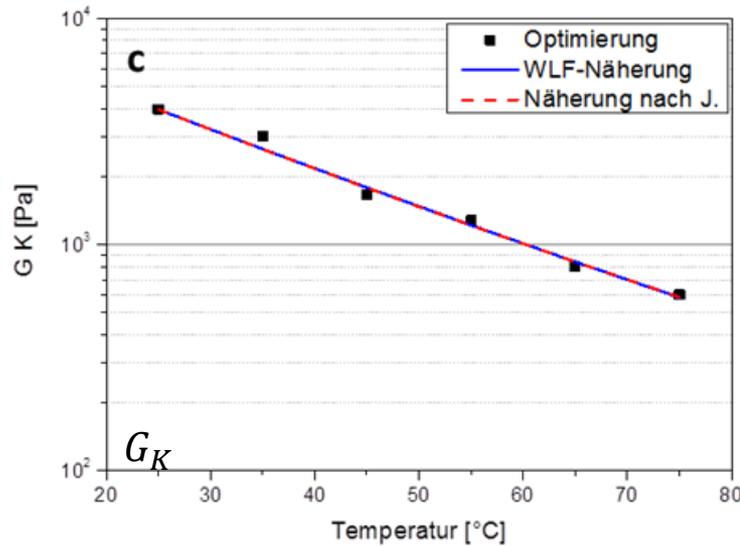
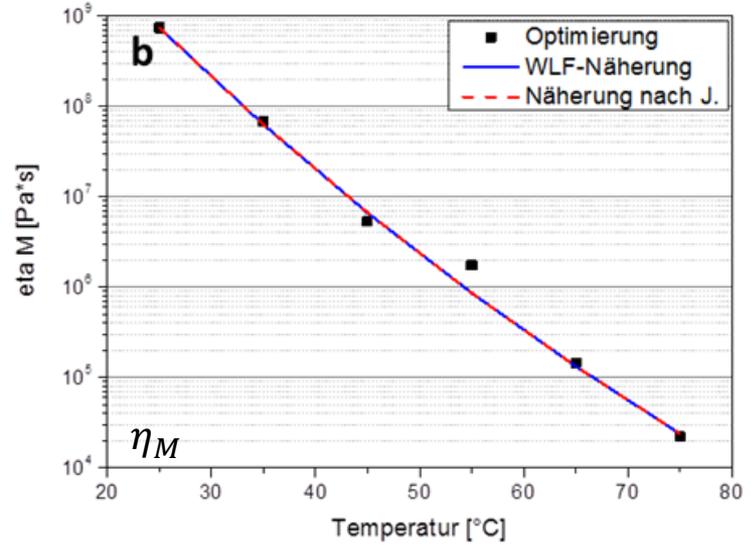
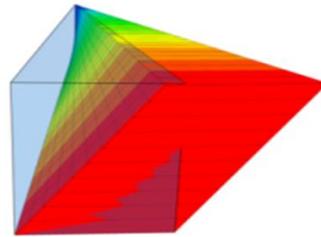
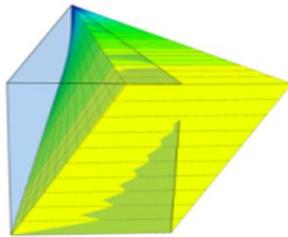
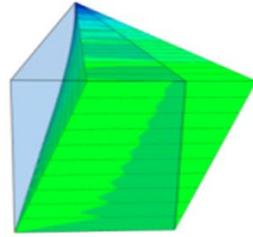
- natural or manufactured material, black, highly viscous liquid (or semi-solid)
- consists of a wide range of hydrocarbons in a colloidal system of high-molecular asphaltenes and low-molecular maltenes
- within the matrix of maltenes, resins and asphaltenes create micelles
- insoluble in water and impermeable for water
- resists most acids and bases, soluble by organic solvents
- good adherence properties
- only small changes in the long term and only small microbiological degradation
- easy design of the properties during manufacturing and in combination with mineral additions (= asphalt)

Bitumen and asphalt

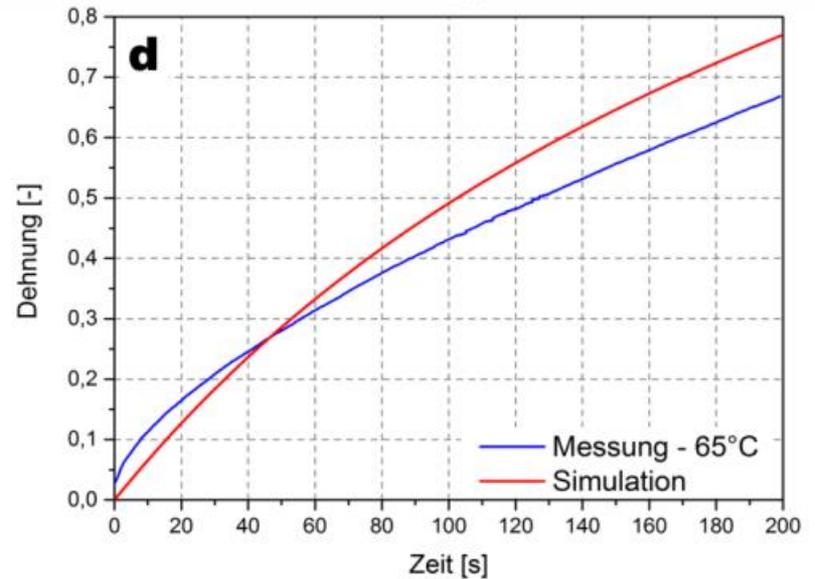
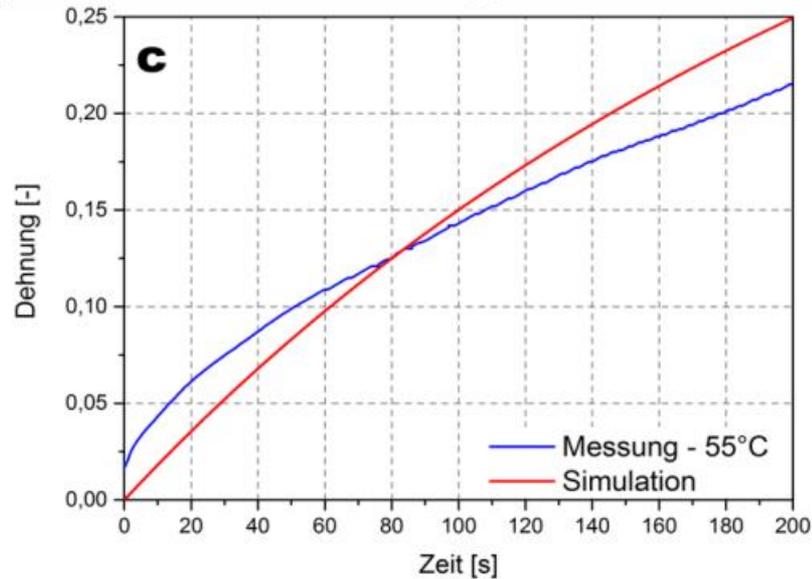
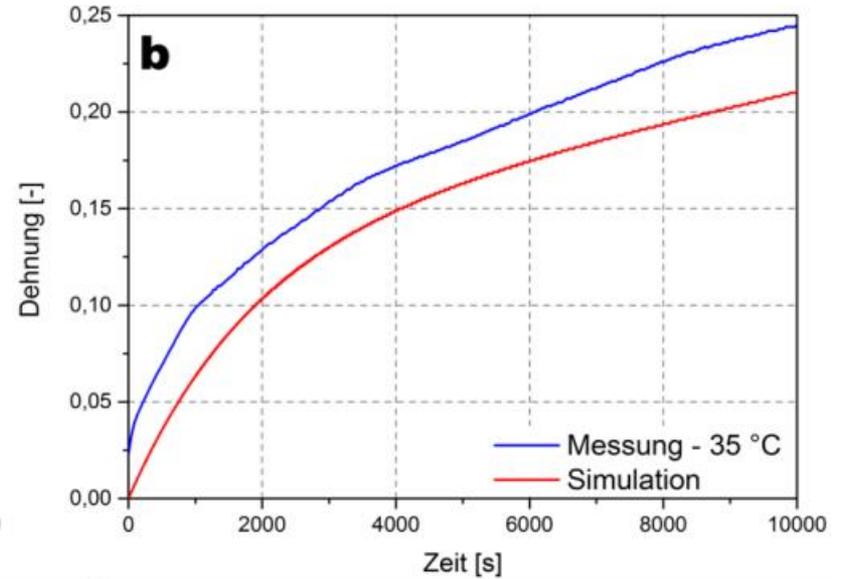
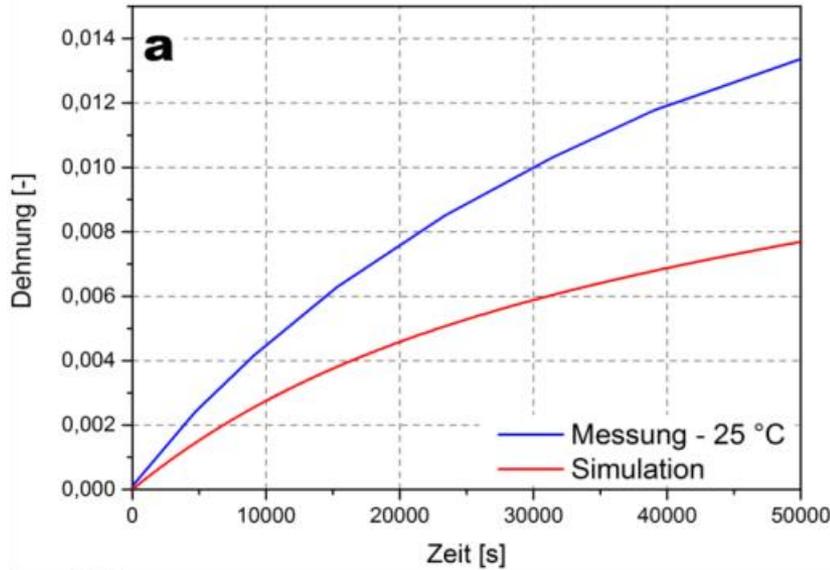
- complex rheological behavior results from complex structure
- material behavior is highly temperature-sensitive
 - stiff behavior at room temperature (asphaltenes create a three-dimensional mesh)
 - elastic behavior during short-term loads/dynamic loads
 - increasing temperatures cracks the mesh
 - behavior changes to visco-elastic and highly viscous for high temperatures
 - viscous behavior at steady loads over long times
- viscosity decreases also under shear strain (=shear thinning)
- Burgers model as basis for description of rheological behavior
- temperature sensitivity and shear thinning implemented into the individual elements



Bitumen and asphalt

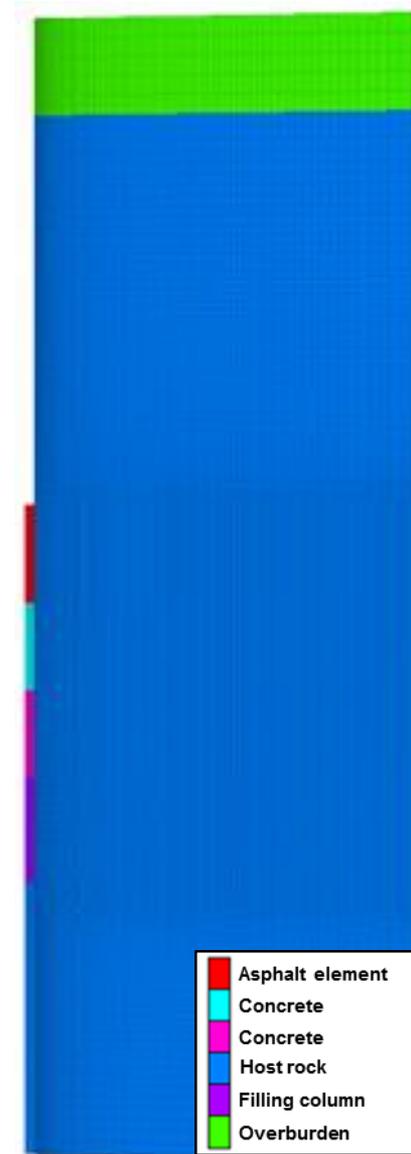


Bitumen and asphalt



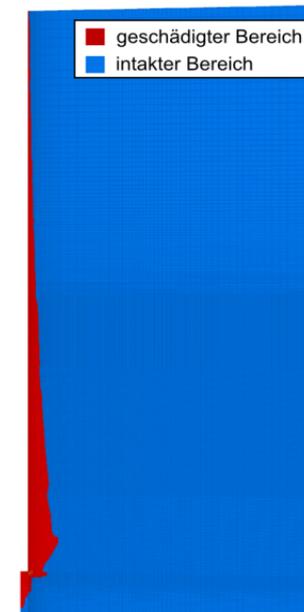
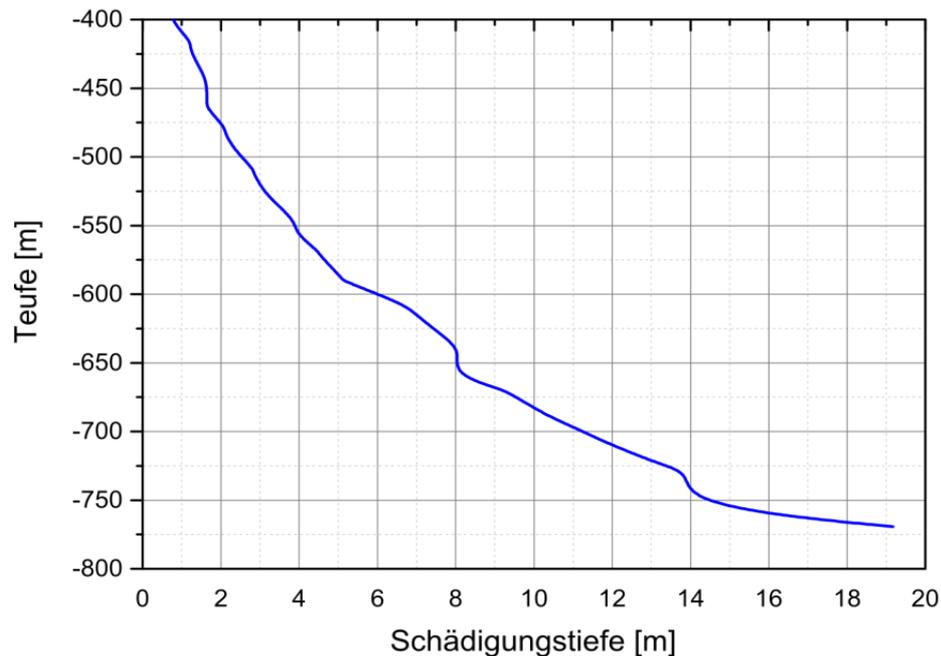
Thermal effects

- Grouting of (hot) bitumen with low viscosity allows easy installation
- Initial temperature of bitumen and asphalt sealing elements varies between 140°C (Sandwich element) and 230°C (conventional poured asphalt)
- Thermal impact creates risk of additional damages to the EDZ and the host rock
- Limited knowledge about the different potential clay formations → numerical simulation (THM):
 - A) Evaluate the extension of the EdZ formed during shaft sinking
 - B) Quantify the damage inside the EDZ by evaluation of the change in permeability
 - C) Quantify the effects of hot asphalt installation by evaluation of the change in permeability

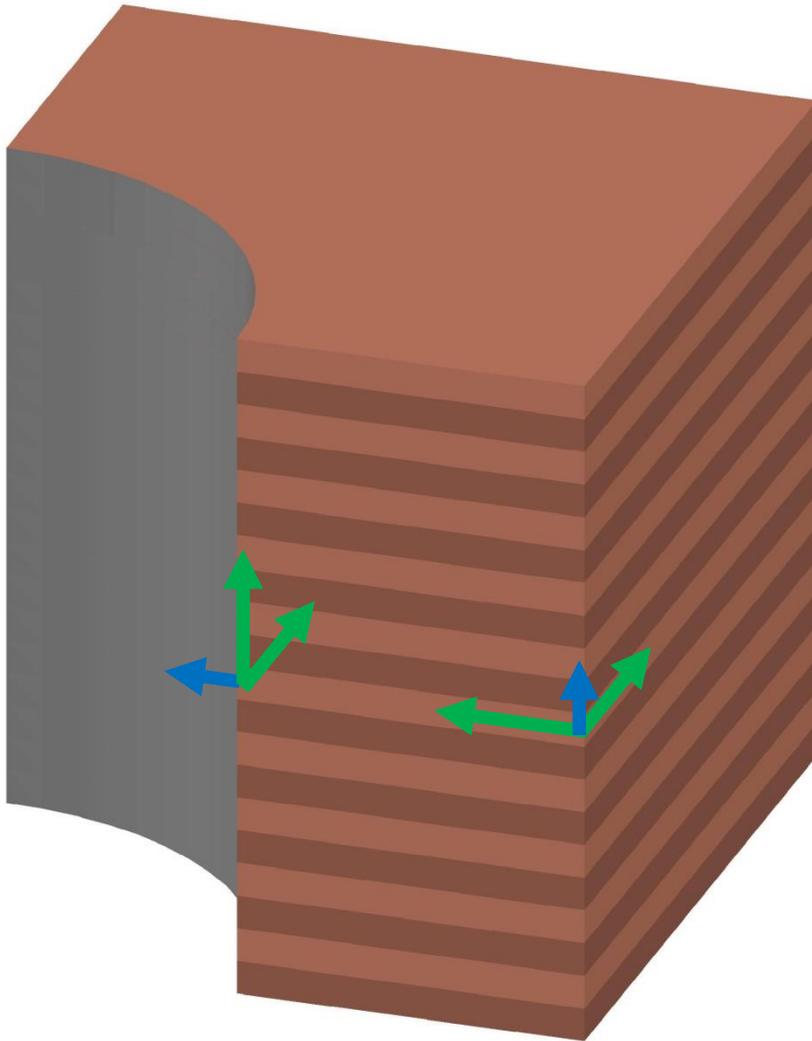


EDZ/EdZ after shaft sinking

- Ubiquitous-Joint model, no lining and no creeping effects after excavation
 - Definition EDZ/EdZ based on Tsang, 2005
 - Damage starts at 50 % of the host rock strength (=dilatancy criteria)
- Excavation disturbed zone (EdZ) up to 19 m at shaft sump
- At sealing location approximately 6 to 7 m



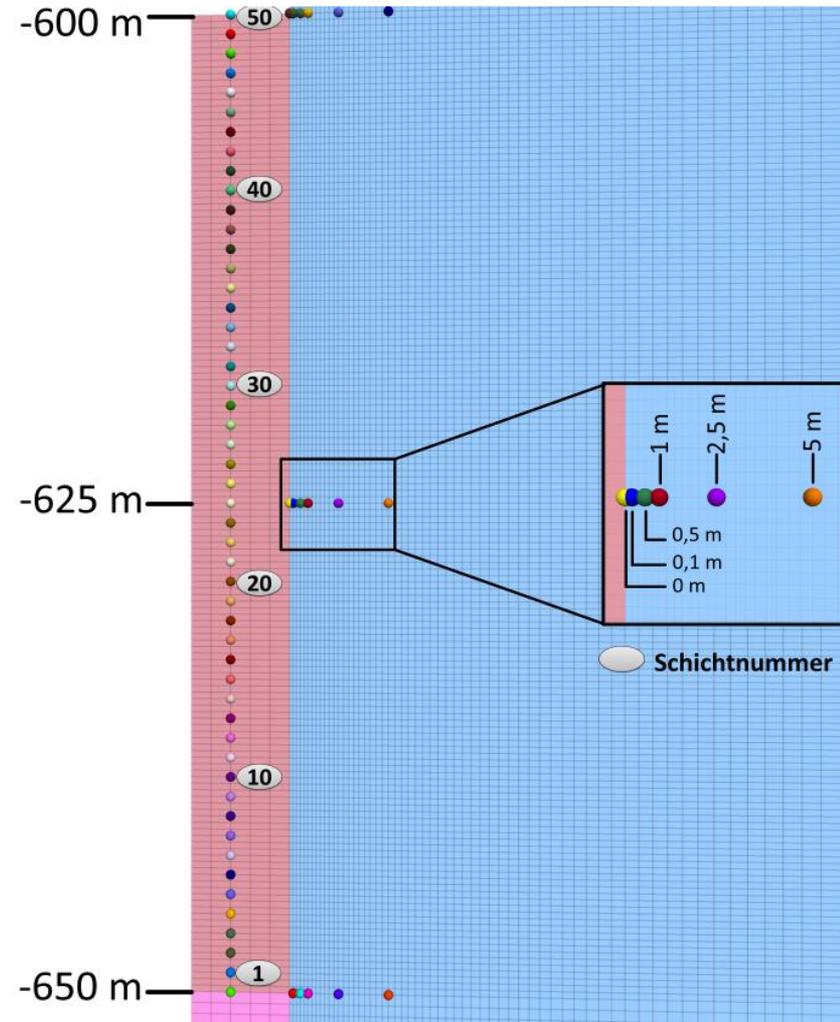
Quantification of EDZ



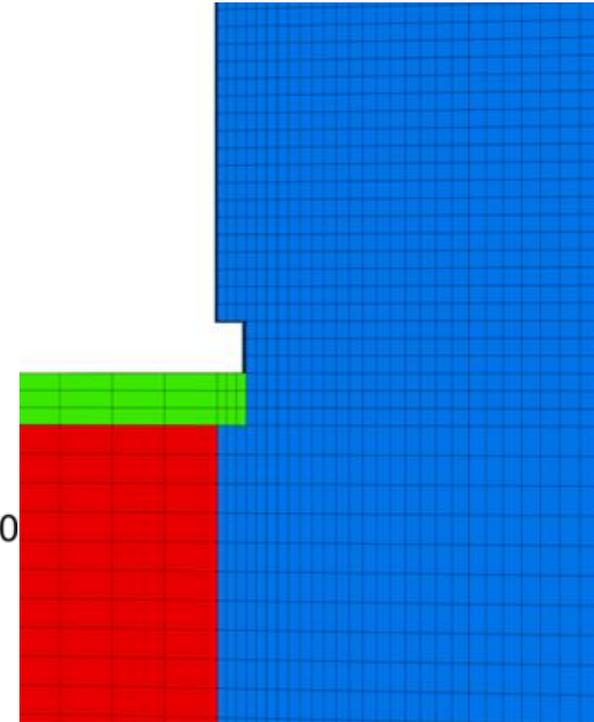
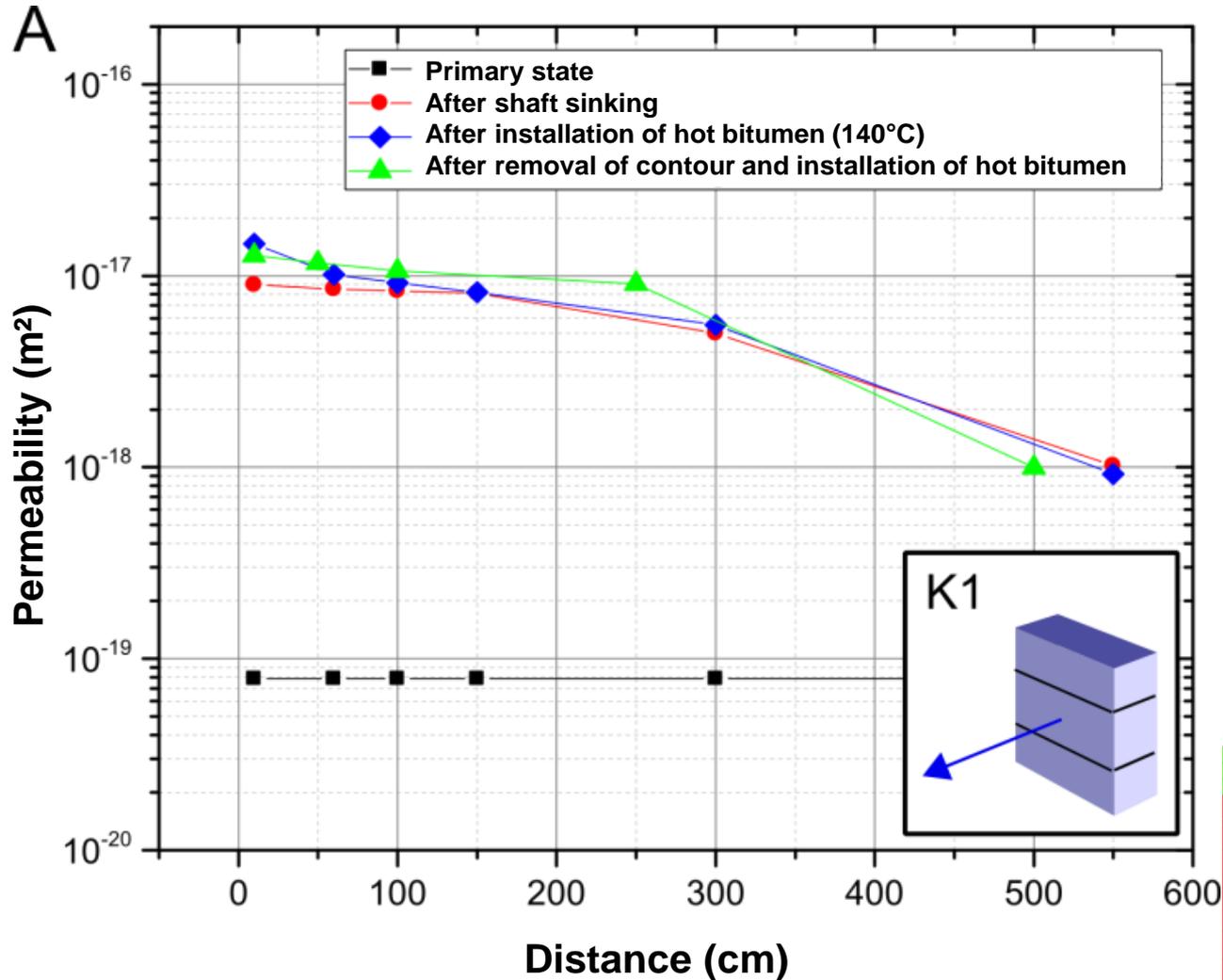
- Initial permeability parallel to bedding higher than perpendicular to bedding (||: $6 \cdot 10^{-19} \text{ m}^2$; \perp : $1,5 \cdot 10^{-20} \text{ m}^2$)
- Permeability is coupled with effective stress and deformation
- HM-coupling developed by DBE TEC
- after shaft sinking, permeability parallel to the shaft contour is higher than perpendicular to shaft contour
- expansion/elongation more relevant than stress relocation
- simulated damage corresponds to radial loosening and radial cracks

Installation of asphalt

- thermal impact next to contour (<1 m)
- increase of permeability close to contour (<0.1 m) due to thermal expansion
- temporary decrease of permeability in some areas (0.6 m) because of compression
- thermal impact produces only marginal additional damage/increase in permeability
- effects are limited to <1m, even in case of instantaneous installation of 50 m bitumen column
- previous damage due to shaft sinking is more relevant



Removal of contour



Summary

- Bitumen and asphalt provide good sealing functions
- Good adherence properties at dry and clean surfaces
- Easy adaptation of material properties possible
- Complex material behavior of the bitumen
- Limitation of functional period prevents risks of potential microbiological degradation
- Currently, three different sealing elements under development
- First small scale in situ tests in boreholes
- THM simulations in regard to thermal impacts predict no significant change in permeability
- Previous damage due to shaft sinking is more relevant

Acknowledgements

Many thanks...

...to all colleagues and participating organizations:



...to the Federal Ministry for Economic Affairs and Energy (BMWi) and the Project Management Agency Karlsruhe (PTKA) of the Karlsruhe Institute of Technology (KIT) for funding the R&D project

Gefördert durch:



aufgrund eines Beschlusses des Deutschen Bundestages



**Thank you
for your attention.**