

# Untersuchungen zu thermischen Aquifer- speichern in Berlin

BY **GUIDO BLÖCHER**, SIMONA REGENSPURG, STEFAN KRANZ, BEN NORDEN, ALI SAADAT  
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### Completed ATES projects:

- ATES-Parlamentsbauten (2005 - 2011)
- ATES-Lüneburg (2011 – 2012)
- ATES Adlershof (2014 - 2017)

### ATES Fasanenstrasse (ATES Berlin) 2012-2016

Efficiency and operational safety of energy systems

### ATES Adlershof (GEOFERN) 2019-2022

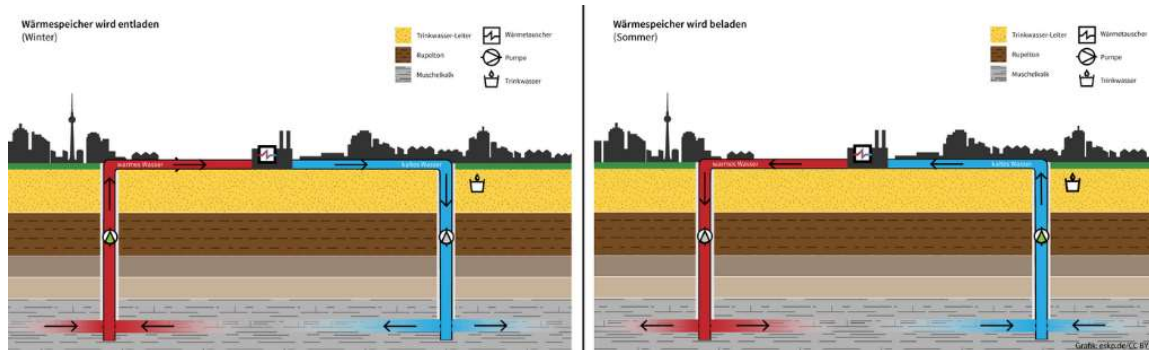
Geothermal District Heat Supply in Berlin

### ATES Spandau (ATES iQ) 2020-2022

Geothermal use of the carbonate rocks in the northern German basin

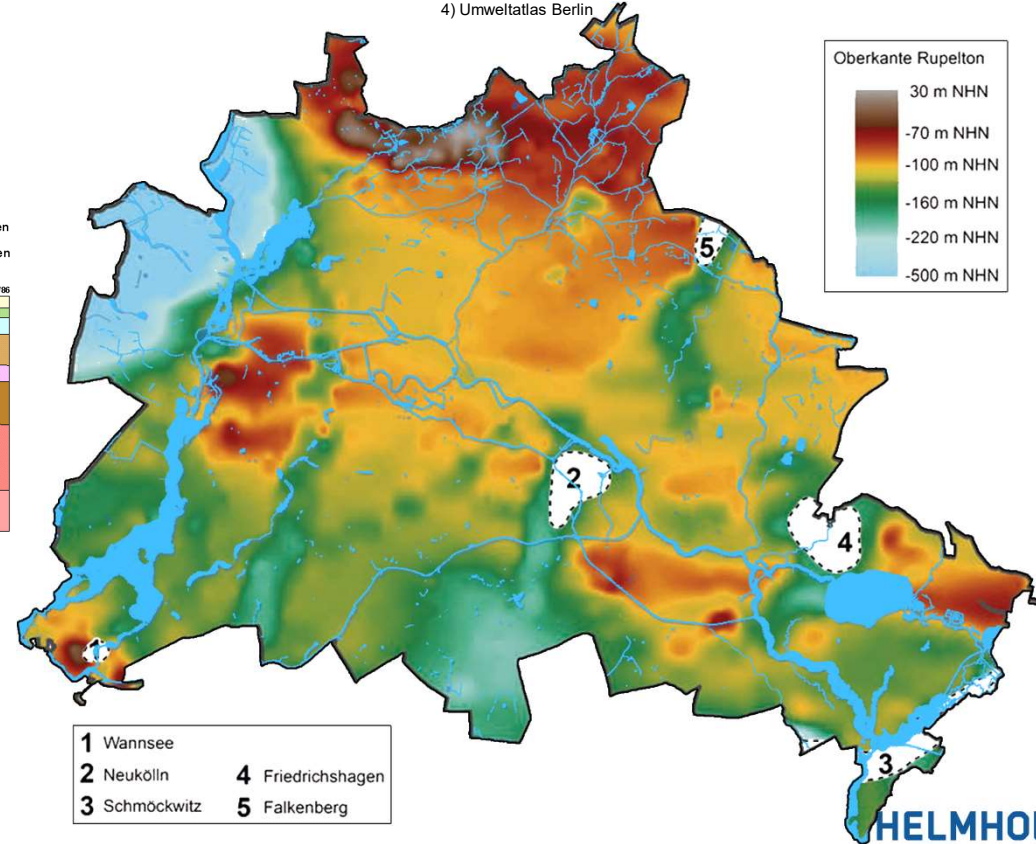
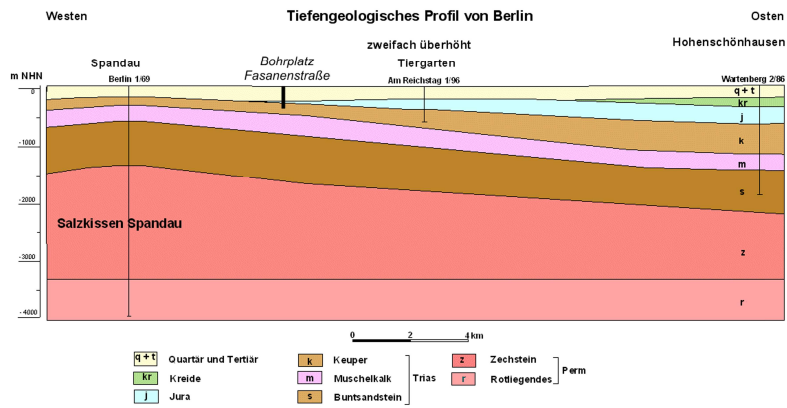
### General Objectives & Tasks:

- Evaluation of reservoir & aquifer potential → geothermal potential map
- Fluid-rock interaction
- Long-term forecast of the thermal, hydraulic, chemical, microbiological processes
- Method development
- Sustainable production & operation
- reliable integration of aquifer systems
- plant technology, heat transformation, energetic efficiency



# ATES – below Oligocene Rupelian clay

- 1) <https://fbinter.stadt-berlin.de>
- 2) Limberg, A., Jonas, O. & Kolberg, A. (2016)
- 3) Geologisches Landesmodell Berlin
- 4) Umweltatlas Berlin



# Part I: ATES – Fasanenstrasse

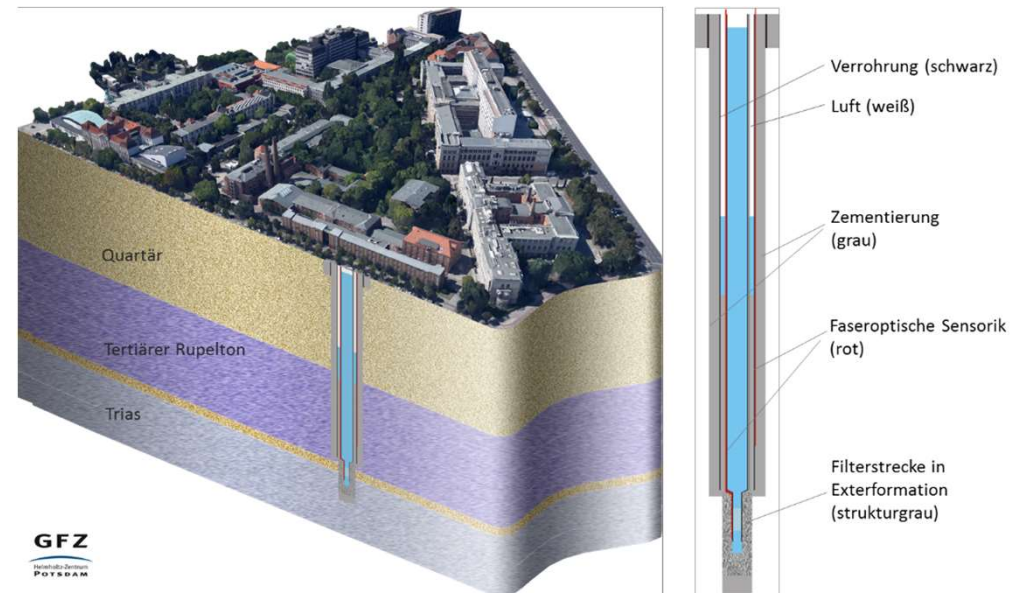
EFFICIENCY AND OPERATIONAL SAFETY OF ENERGY SYSTEMS

PROJEKTLEITUNG: ALI SAADAT

# General Introduction

## Case Study

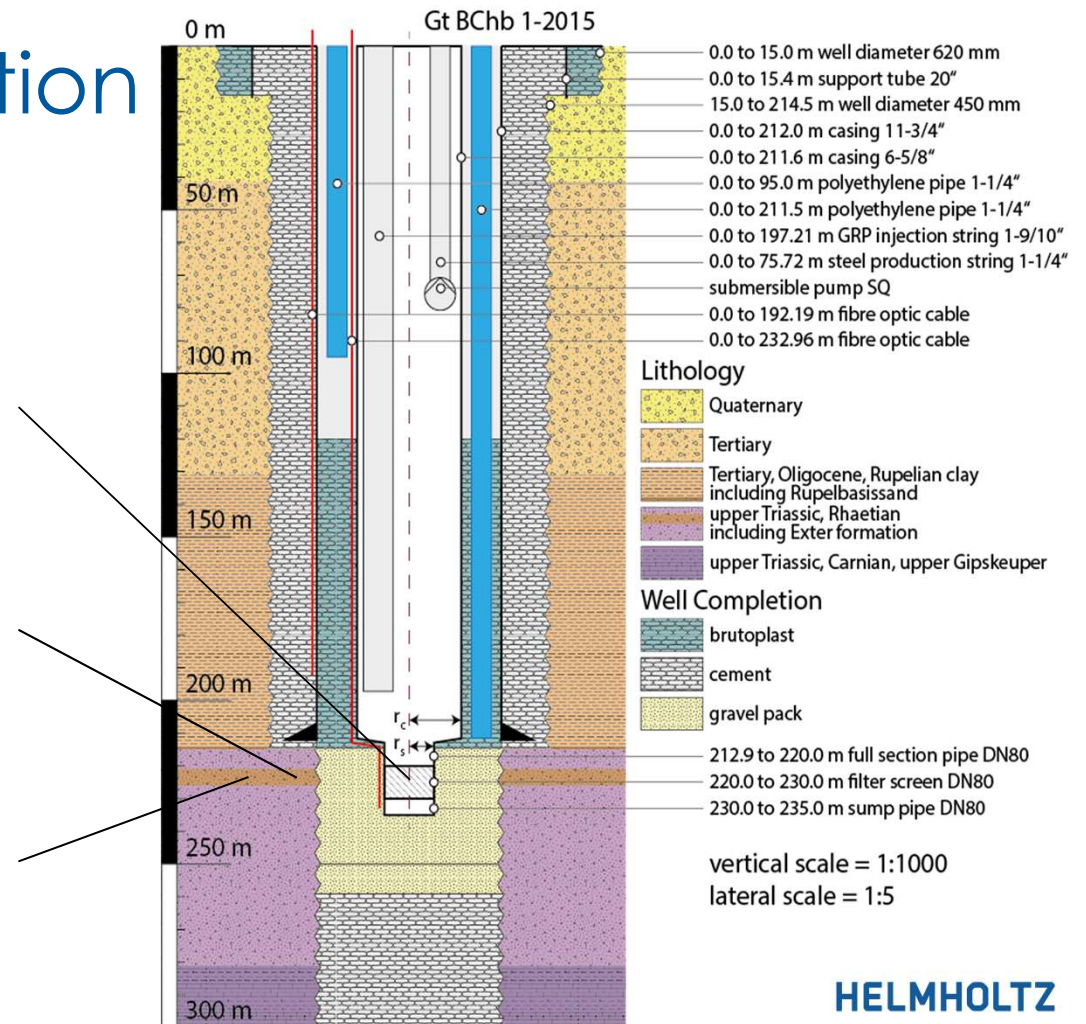
- **Wellbore Gt BChb 1/2015 at TU Campus:**
  - Drilled in 2015
  - Submersible pump installed in 75 m
  - Filter from 220 to 230 m
  - Radius at reservoir depth is 4 cm
- **Exter formation (Keuper - Triassic)**
  - Fine grained sandstone
  - Depth: 222-226 m
  - Aquifer thickness only 4 m
  - Confined aquifer
  - Hydraulic head at the surface



# General Introduction

For a potential usage of the Exter formation as an ATEs we have to know:

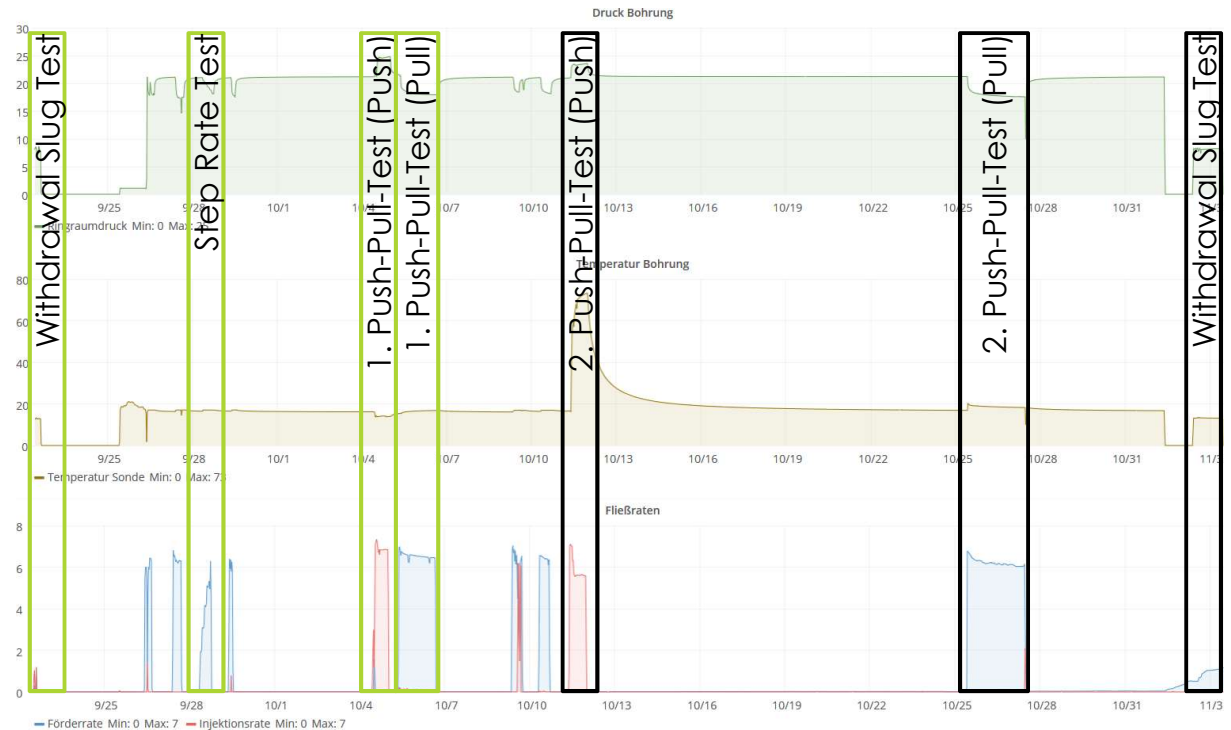
- Well performance
  - Productivity index  $PI$
  - Specific productivity  $C_s$
  - Skin effect
- Flow Parameter
  - Porosity  $\varphi$
  - Hydraulic conductivity  $k_f$
  - Transmissivity  $T$
  - Coefficient of storage  $S$
- Transport Parameter
  - Ground-water velocity  $v_a$
  - Hydraulic gradient  $I$
  - Dispersivity  $\alpha$



# General Introduction

- **Between 09/2017 and 11/2017 several hydraulic tests were performed:**
  - 7 Slug-Withdrawal Tests
  - 1 Step-Rate Test
  - 2 Push-Pull-Test
- During this talk we analyse
  - 1 Slug-Withdrawal Tests
  - 1 Step-Rate Test
  - 1 Push-Pull-Test

**Note:** All presented analysis are performed for a confined aquifer and a perfect well. For unconfined aquifers and imperfect wells corrections regarding drawdown and filter screen must be considered.



# Step-Rate Test

## Method:

- **Step 1:**  
installing submersible pump and wait for stabilized pressure conditions
- **Step 2:**
  - series of constant-rate productions with rates increasing from low to high in a step wise fashion
  - each constant-rate step is normally of equal time length
- **Step 3:**  
water level or pressure monitoring until pressure equilibrium

deposing water



water level monitoring





# Step-Rate Test

**Analysis Productivity Index  $PI$  and specific productivity  $C_s$ :**

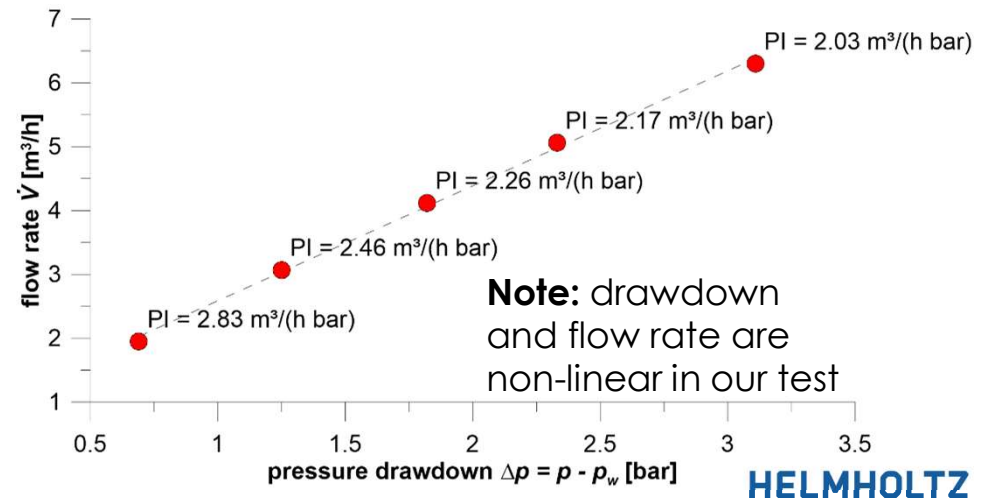
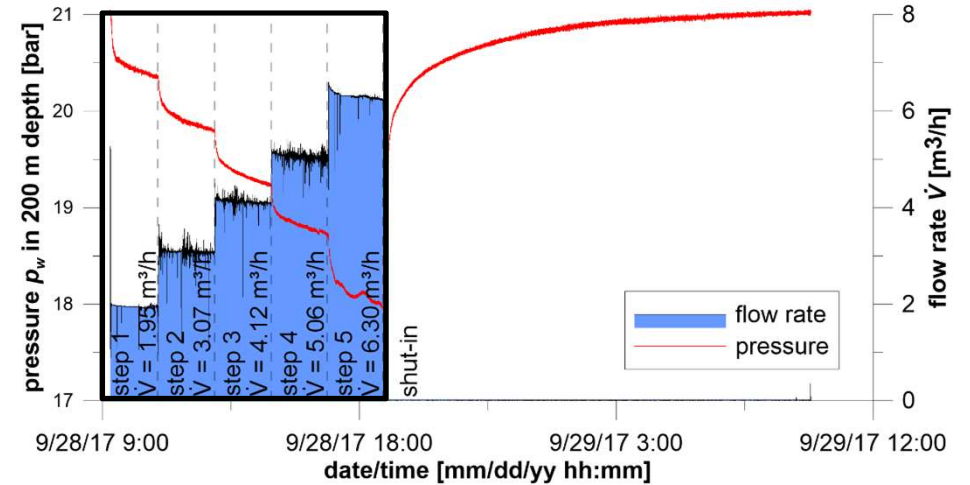
- **Step 1:**  
plotting flow rate  $\dot{V}$  and corresponding flow bottom hole pressure  $p_{wf}$
- **Step 2:**  
calculating productivity index  $PI$  for each step in terms of pressure drawdown

$$PI = \frac{\dot{V}}{p - p_w} = \frac{\dot{V}}{\Delta p}$$

or specific productivity in terms of water table drawdown

$$C_s = \frac{\dot{V}}{s_w}$$

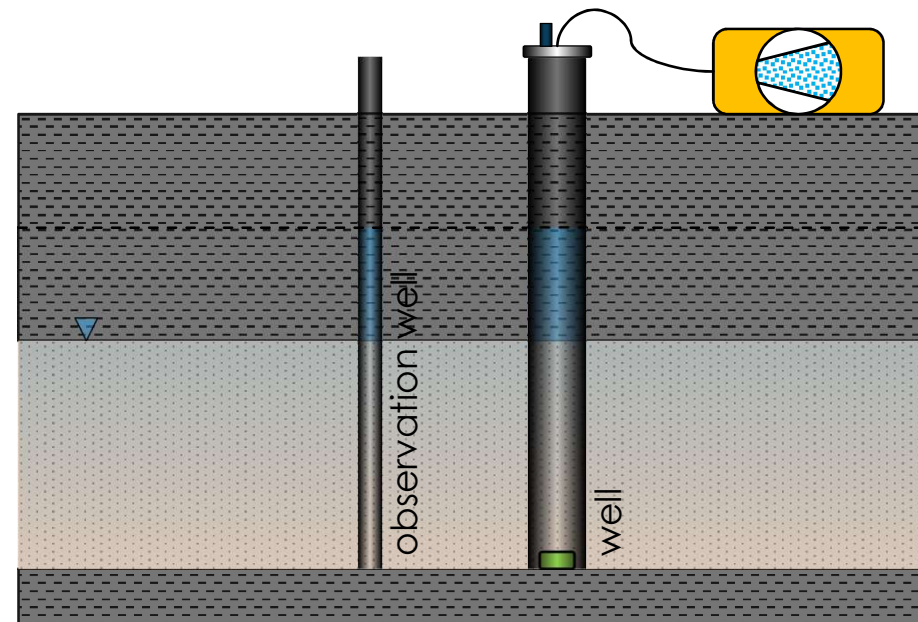
**Note:** For unsteady flow condition the productivity is time depending







# Slug-Withdrawal Test

## Requirements:

- Air compressor attached to the well head
- Well has to be gas tight
- Gas valve allowing fast pressure release
- Water level or pressure is monitored

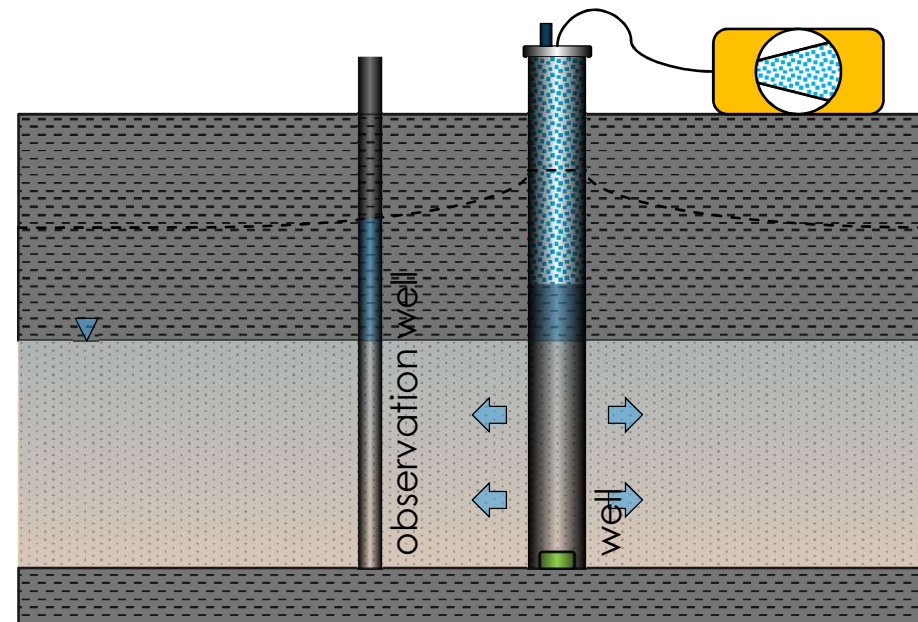






-  aquifer, water-bearing permeable rock
-  aquiclude (or aquifuge), impermeable area underlying or overlying an aquifer
-  air compressor
-  pressure transducer

# Slug-Withdrawal Test

## Method:

- **Step 1:**  
Increasing air pressure inside the wellbore  
by air compressor  
(often fluctuating pressure conditions →  
not to analyze)



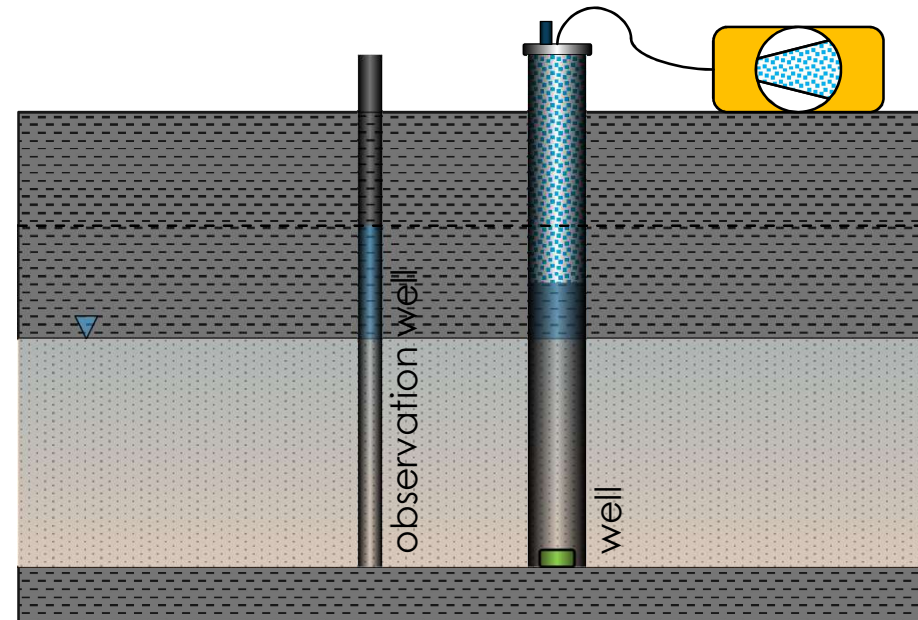
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# Slug-Withdrawal Test

## Method:

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Increasing air pressure inside the wellbore  
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- **Step 2:**  
water level or pressure monitoring until  
pressure equilibrium

$$p_A = \rho_w * g * h + p_g$$

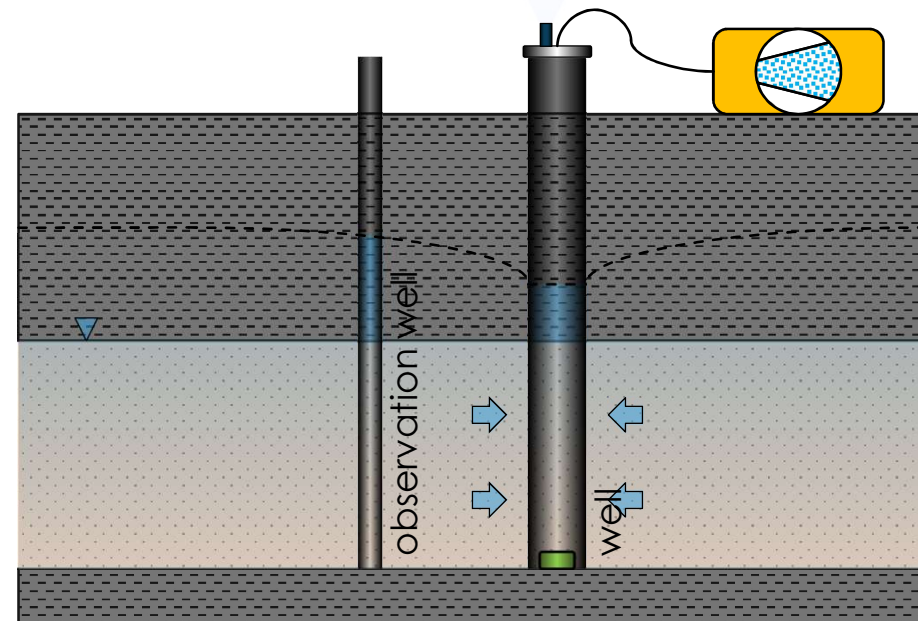






-  aquifer, water-bearing permeable rock
-  aquiclude (or aquifuge), impermeable area underlying or overlying an aquifer
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$$p_A = \rho_w * g * h + p_g$$
- **Step 3:**  
sudden release of air pressure

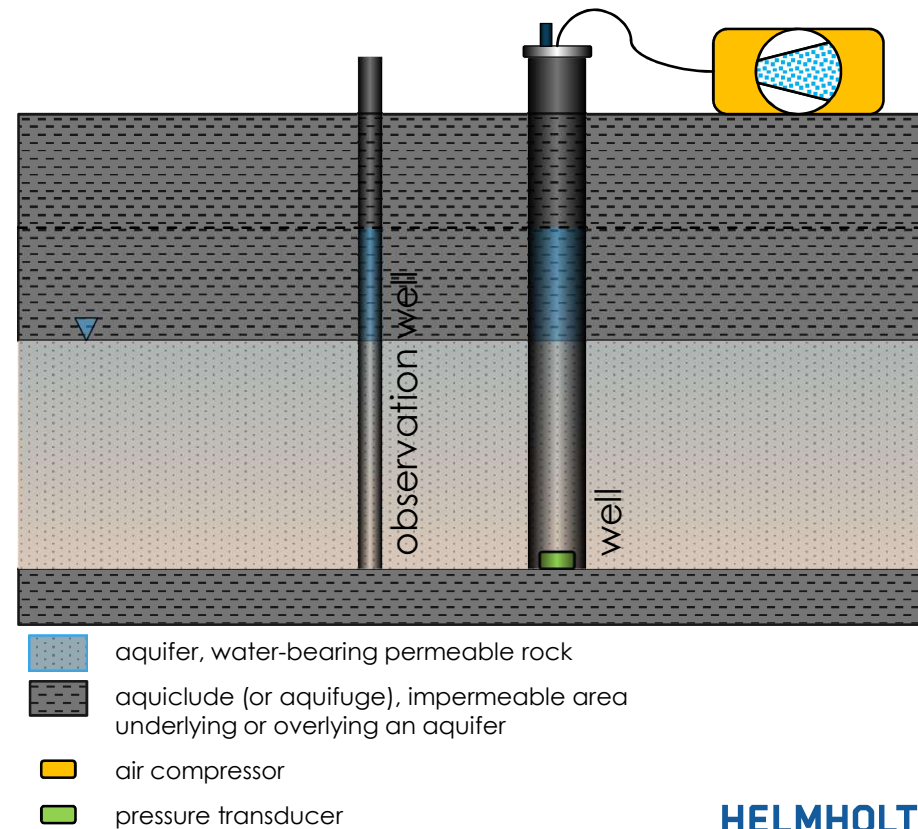


-  aquifer, water-bearing permeable rock
-  aquiclude (or aquifuge), impermeable area underlying or overlying an aquifer
-  air compressor
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# Slug-Withdrawal Test

## Method:

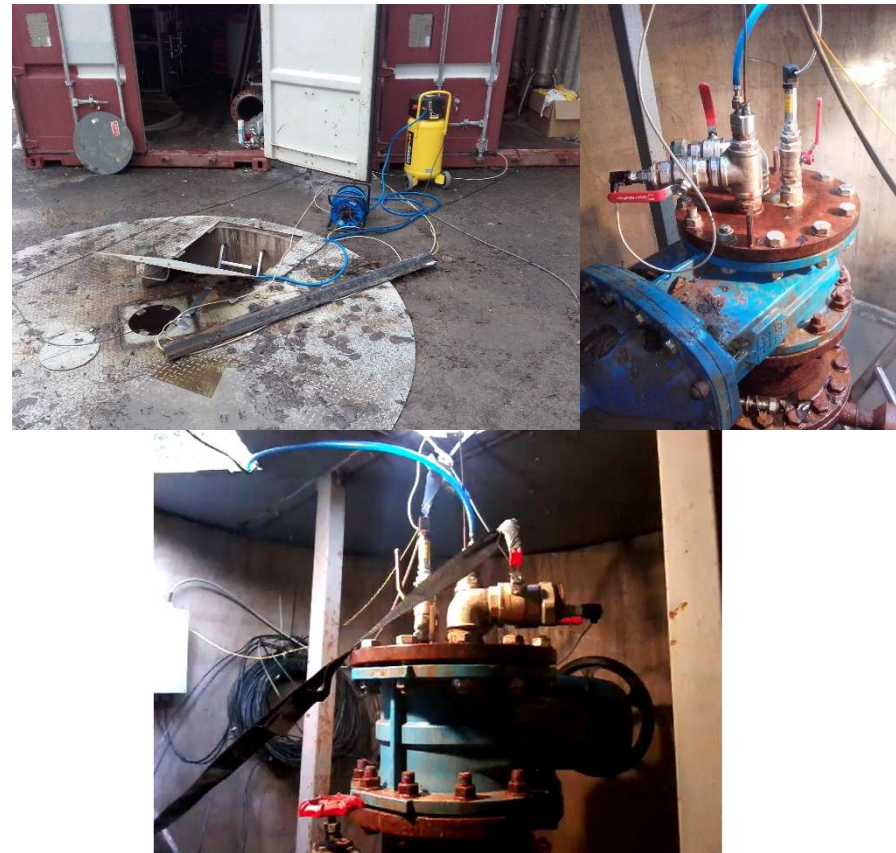
- **Step 1:**  
Increasing air pressure inside the wellbore by air compressor  
(often fluctuating pressure conditions → not to analyze)
- **Step 2:**  
water level or pressure monitoring until pressure equilibrium  
$$p_A = \rho_w * g * h + p_g$$
- **Step 3:**  
sudden release of air pressure
- **Step 4:**  
water level or pressure monitoring until pressure equilibrium



# Slug-Withdrawal Test

## Method:

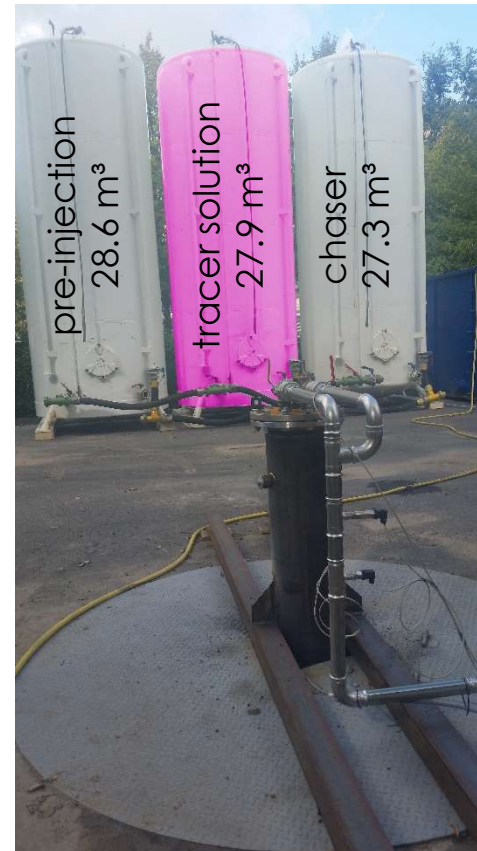
- **Step 1:**  
Increasing air pressure inside the wellbore by air compressor to 5 bar
- **Step 2:**  
water level or pressure monitoring until pressure equilibrium
$$p_A = \rho_w * g * h + p_g$$
- **Step 3:**  
sudden release of air pressure
- **Step 4:**  
water level or pressure monitoring until pressure equilibrium



# Push-Pull Test

## Analysis Dispersivity $\alpha$ :

- **Push phase:**
  - total injection volume  $V_{inj} = 83.8 \text{ m}^3$
  - After  $28.6 \text{ m}^3$  the tracer starts.
  - The injected volume of the tracer and the subsequent chaser is  $55.2 \text{ m}^3$
  - 160 g of eosin were admixed
  - The accessed radius  $r_{max}$  is 4.7 m considering an aquifer thickness of 4 m and a porosity of 0.2
- **Pull phase:**
  - total produced volume  $V_{pro} = 315.4 \text{ m}^3$
- **Determination of tracer concentration:**
  - Eosin concentration is determined by laboratory measurements (push & pull) and GGUN-FL30 flow-through field fluorimeter (pull)



spectral lab fluorimeter  
QM-4/2005



flow-through field fluorimeter  
GGUN-FL30





# Push-Pull Test

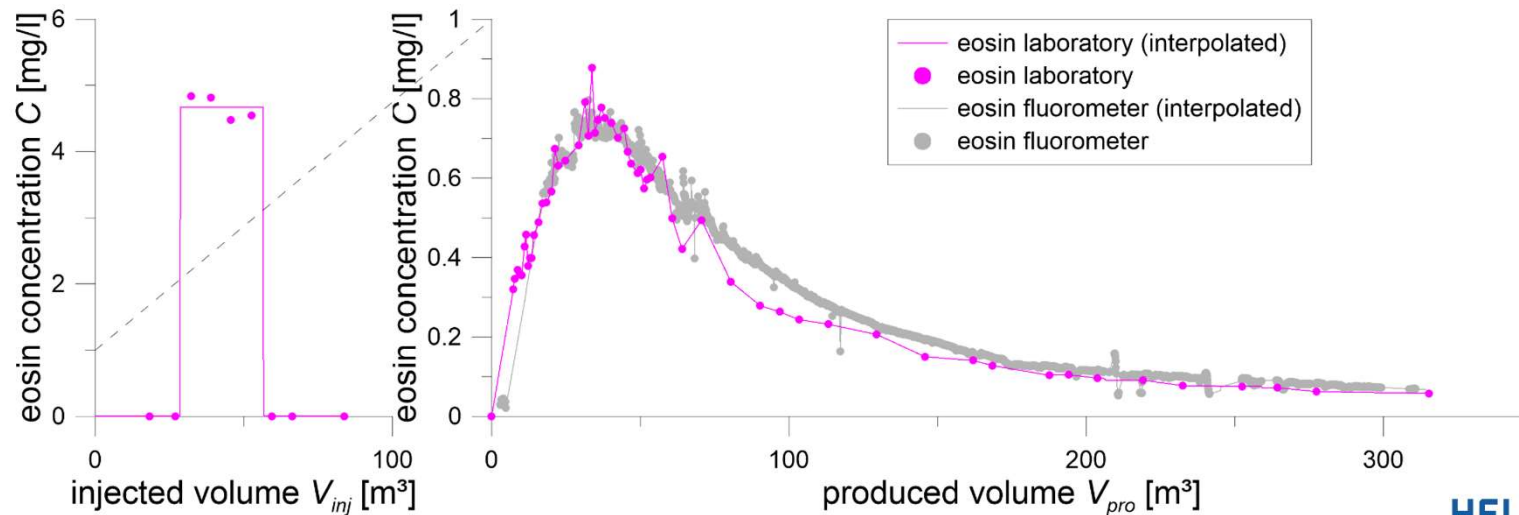
## Analysis Dispersivity $\alpha$ :

### • Push phase:

- measured eosin concentration  $C_0 = 4.668$  mg/l
- Injected eosin mass  $m = 130.7$  g (81.7% of admixed mass)

### • Pull phase:

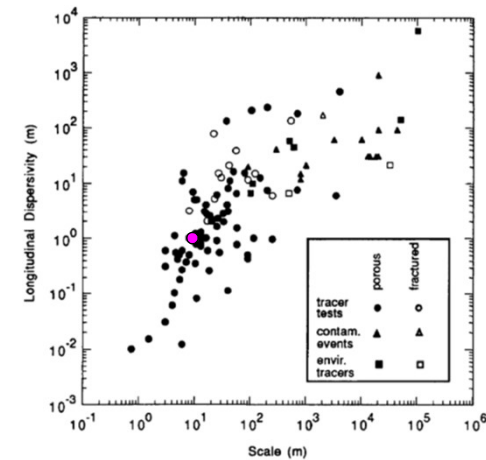
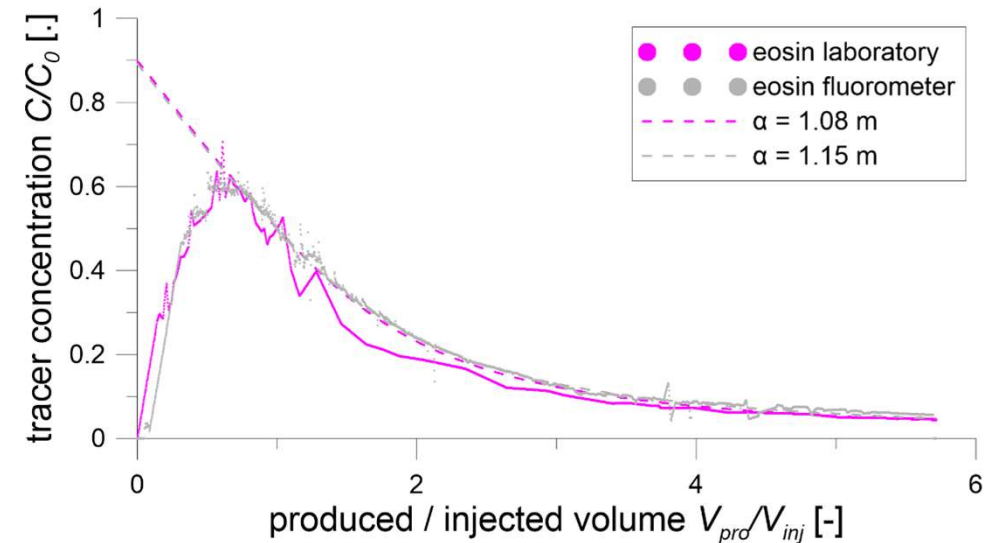
- Recovery determined by laboratory measurements: 73.3 g (56.1%)
- Recovery determined by fluorimeter measurements: 79.3 g (60.7%)



# Push-Pull Test

## Analysis Dispersivity $\alpha$ :

- eosin concentration push phase:  
 $C_0 = 4.668 \text{ mg/l}$
  - theoretical eosin concentration at  $\frac{V_{pro}}{V_{inj}} = 1$ :  
 $\frac{C}{C_0} = 0.5 \rightarrow C = 2.334 \text{ mg/l}$
  - measured eosin concentration at  $\frac{V_{pro}}{V_{inj}} = 1$ :  
 $\frac{C}{C_0} = 0.13 \rightarrow C = 0.61 \text{ mg/l}$
- attenuation factor: **3.8** (which must be considered for type curve analysis)
- Type curve analysis indicates a longitudinal dispersivity  $\alpha$  of 1.08 to 1.15 m for a transport length (scale) of 9.4 m

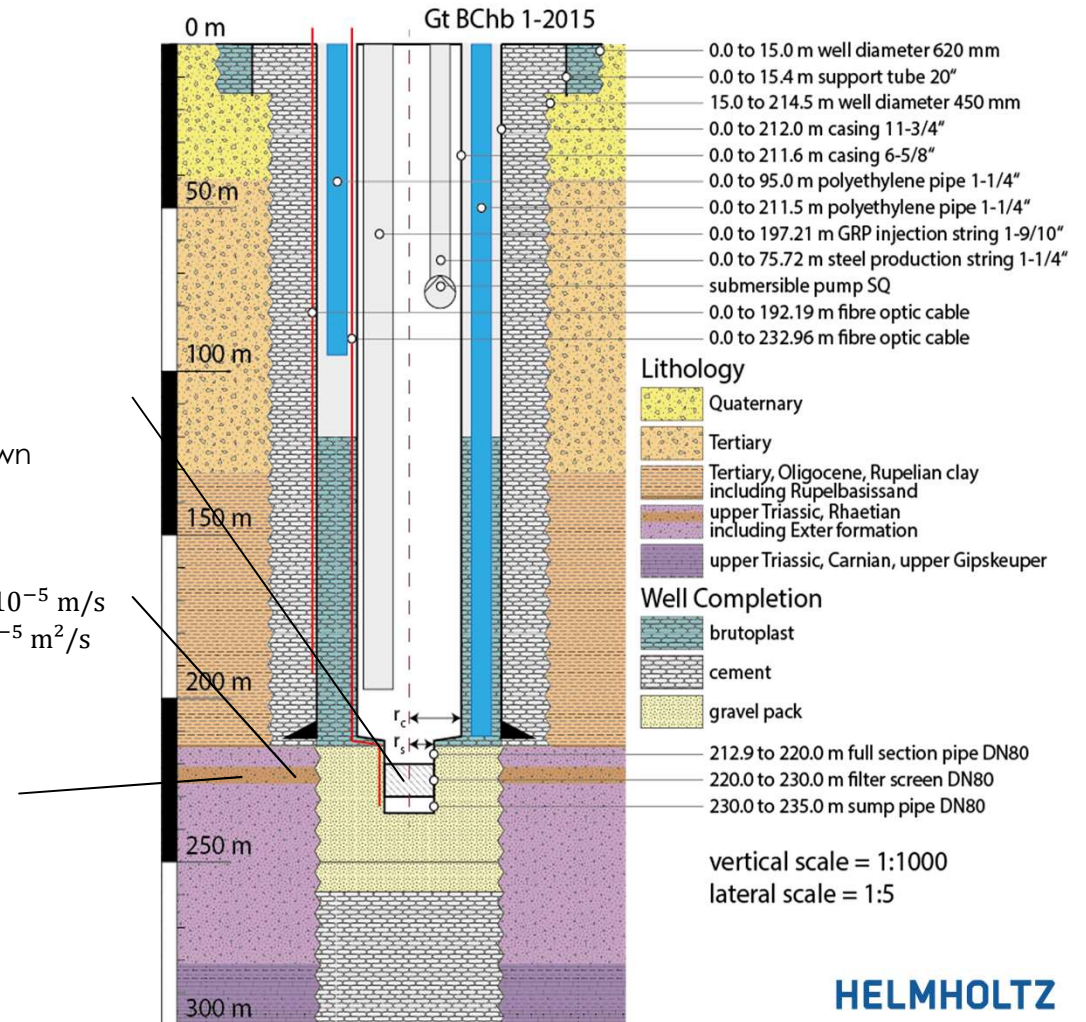


Gelhar et al., 1992

# Results

## The Exter formation is suitable for scientific purposes and ATEs demonstration:

- Well performance
  - Productivity index  $PI = 2.8 \text{ m}^3/(\text{hbar})$
  - Specific productivity  $C_s = 0.28 \text{ m}^2/\text{h}$
  - Skin effect 12.4 m at 31.1 m drawdown
- Flow Parameter
  - Porosity  $\varphi = 0.2$
  - Hydraulic conductivity  $k_f = 0.8 \times 10^{-5} \text{ to } 2.36 \times 10^{-5} \text{ m/s}$
  - Transmissivity  $T = 3.2 \times 10^{-5} \text{ to } 9.5 \times 10^{-5} \text{ m}^2/\text{s}$
  - Coefficient of storage  $S = 3.54 \times 10^{-9}$
- Transport Parameter
  - Ground-water velocity  $v_a = 6.64 \times 10^{-5} \text{ m/s}$
  - Hydraulic gradient  $I = 0.56$
  - Dispersivity  $\alpha = 1.08 \text{ to } 1.15 \text{ m}$





# Part II: Berlin – Spandau

GEOHERMAL USE OF THE CARBONATE ROCKS IN THE NORTHERN GERMAN BASIN

PROJEKTLEITUNG: GUIDO BLÖCHER

## Subsequent use of Berlin natural gas storage facility



### Opportunity – Green Campus Berlin

- ATEs
- Gas storage
- Hydrothermal use
- Raw material extraction



### Available geological

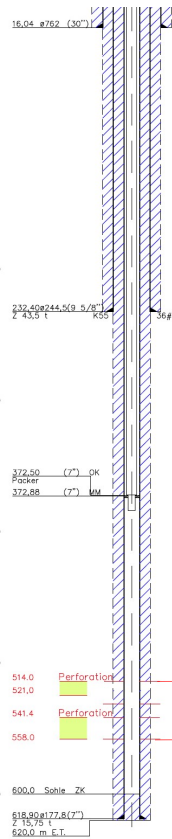
- Seismic campaign
- Geological model
- Drill cores / well profiles
- Well logging data
- Petro-physical properties, e.g. porosity & permeability
- Fluid (liquid & gas) chemical analysis

### Wells:

- 16 wells in Bundsandstein formation
- 1 well in Rotliegend formation
- 4 wells in Muschelkalk formation

### General:

- Decades of operational experience
- well-maintained technical system
- established location in urban areas
- good networking with stakeholders (politics, supervisory authorities, market partners and suppliers / service companies)



**Folgende Art und Reihenfolge der Teste wurden durchgeführt:**

15.-16. April 2021

Slug-Withdrawal Teste jeweils an der BH02 und BH03

01.-08.07.2021

Leistungspumpversuch an der Bohrung BH03

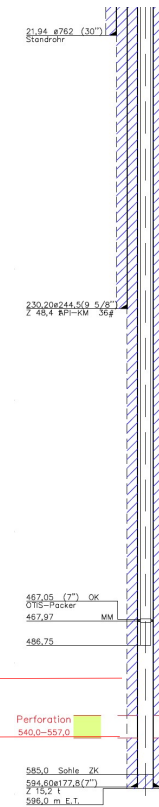
Pumpversuch mit elektrischer Tiefenpumpe an der BH03

Tiefenprobenahme

Injektionsexperiment an der BH03

**Muschelkalk Formation**

**Die Testarbeiten wurden durch ein hydro-chemisches, physiko-chemisches und mikrobielles Monitoringprogramm begleitet.**



Slug-Withdrawal Teste an der Bohrung BH03

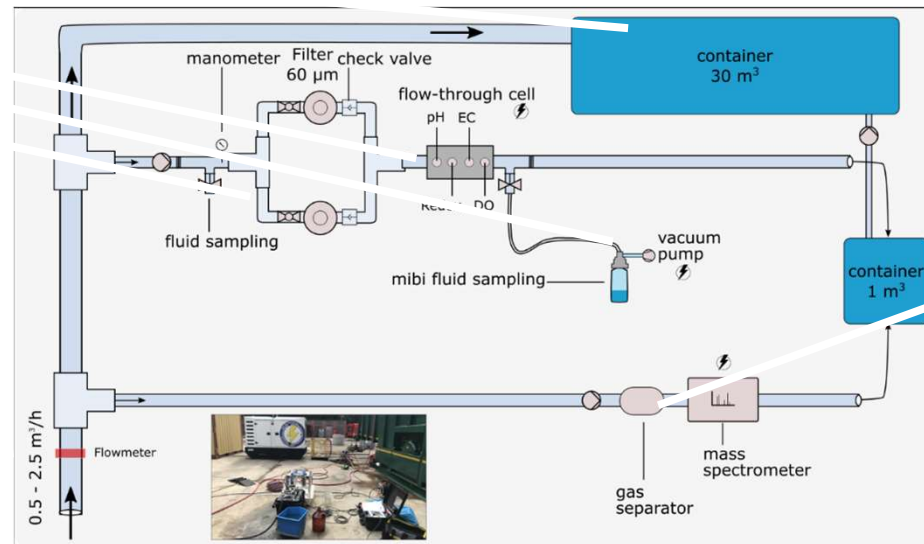
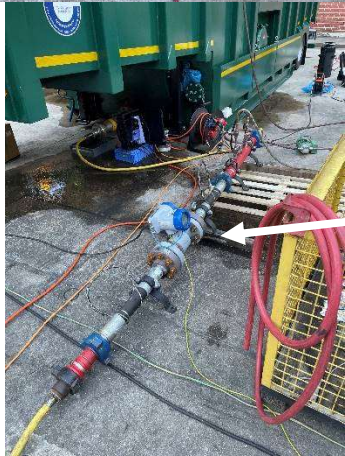
Berlin H2/89



Berlin H3/91



# Hydraulische Tests mit hydro-chemischen, physiko-chemischen und mikrobiellen und Gas-Monitoringprogramm



# 5-stufiger Leistungstest an der BH03

Am 05.07.2021 zwischen 14:00 Uhr und 22:30 Uhr ein Leistungstest mit 5 Stufen durchgeführt

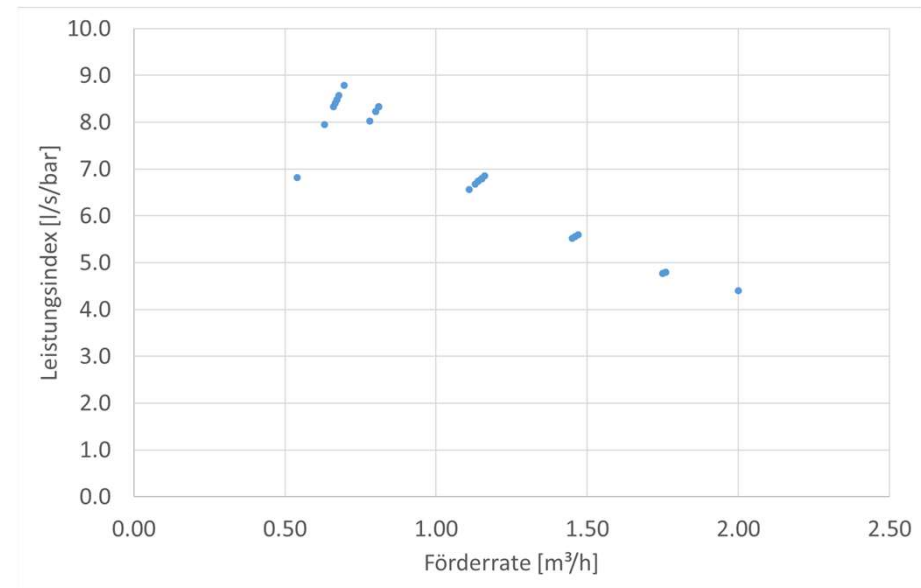
Im Vorfeld wurde der Head-Space von ca. 10 m mit Stickstoff ausgespült  
eingesetzte Förderpumpe wurde am Strang auf 61 m unter GOK eingebaut

Volumenströme von 0.8, 1.15, 1.45, 1.75 und 2 m<sup>3</sup>/h

Stufenlänge von jeweils 2 Stunden

- Beim Beginn der 5. Stufe kam es zu einem Pumpenausfall, welcher den Leistungstest beendete.

Während des Leistungspumpversuches wurden kumulativ 9.6 m<sup>3</sup> Fluid gefördert



Produktivitätsindex von anfänglich **8-9 l/s/bar** bei zunehmender Förderrate Wert von **4.5 l/s/bar**



# 16-stündiger Produktionstest an der BH03

Ausbau der defekten Tiefenpumpe und dem Einbau einer Ersatzpumpe auf 26 m unter GOK

Test wurde am 06.07.2021 um 14:30 Uhr gestartet und am 07.07.2021 um 07:00 Uhr beendet

Förderrate lag durchschnittlich bei ca. 1.75 m<sup>3</sup>/h

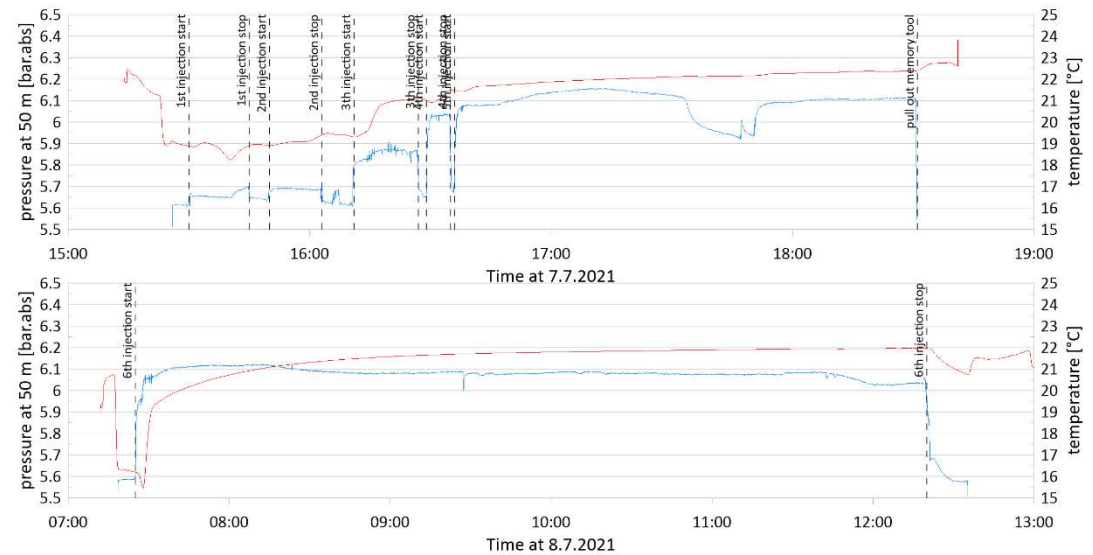
Während des Produktionstest wurden ca. 29.3 m<sup>3</sup> gefördert und unter Stickstoffatmosphäre auf dem Platz gestapelt

**Der Produktionstest an der BH03 wurden durch ein hydrochemisches Fluidmonitoring, ein Gasmonitoring und eine mikrobiologische Charakterisierung des geförderten Thermalfluides begleitet.**

# Injektionstest (07.-08.07.2021)

Memory-Tool auf 50 m Teufe abgehängt  
 37.6 m<sup>3</sup> nach Filterung re-injiziert  
 Re-injektion mit Raten von anfänglich 4.75 m<sup>3</sup>/h (fallend auf 4.5 m<sup>3</sup>/h)  
 Injektivitätsindex lag anfänglich bei ca. 10 l/s/bar und reduzierte sich auf ca. 2.5 l/s/bar zum Ende des Injektionstests

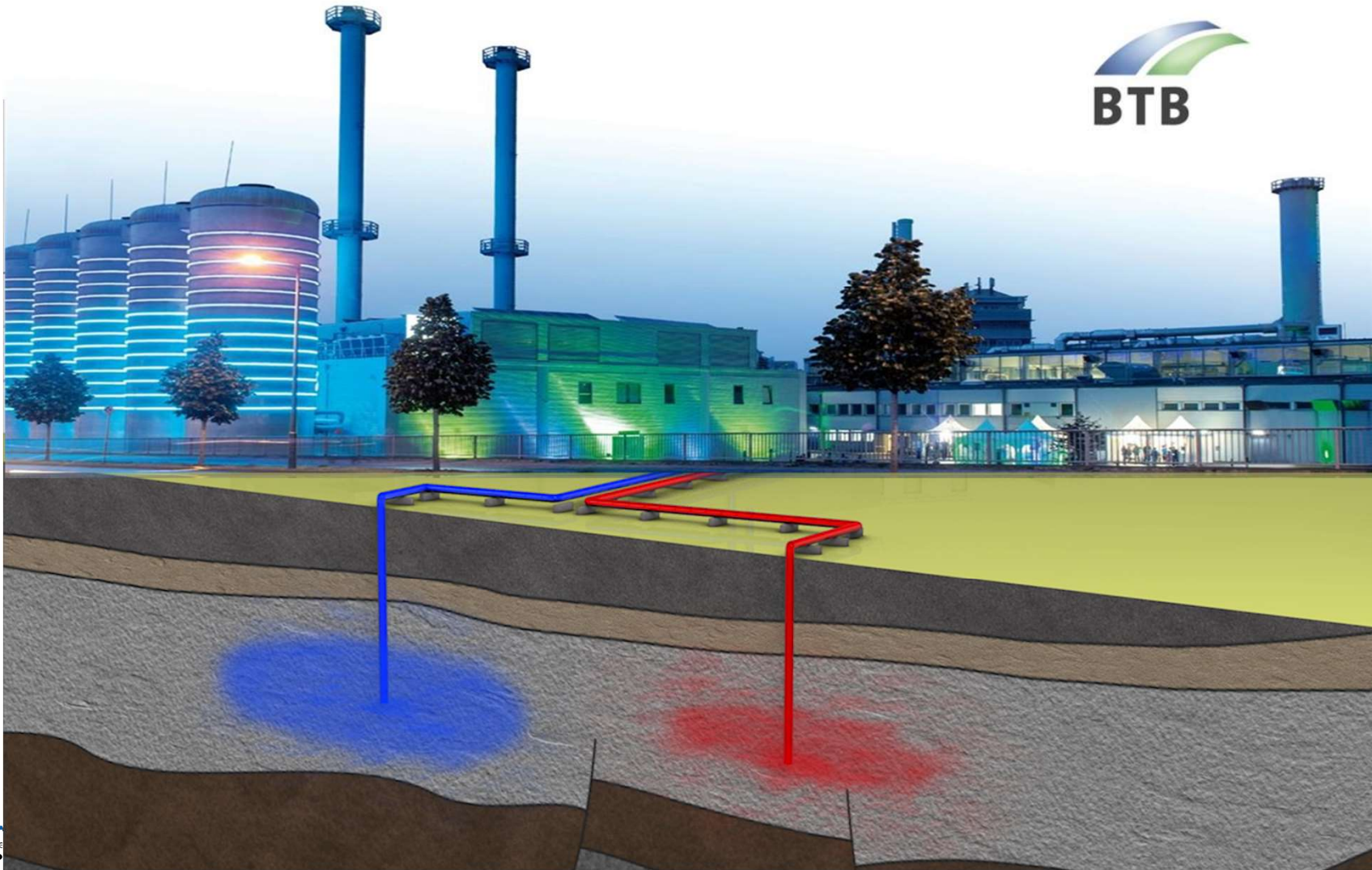
**Leistungsindex > 1 l/s/bar → sehr gute hydraulische Verhältnisse für hydrothermale bzw. ATEs Nutzung**

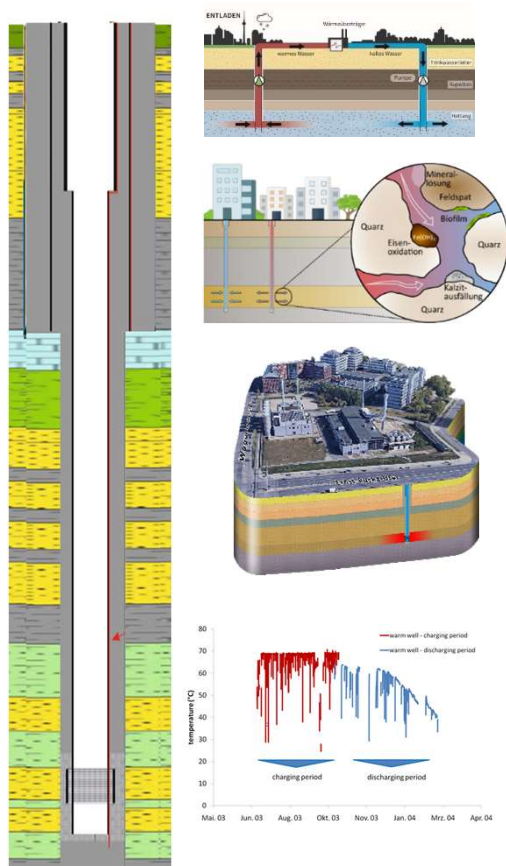


# Part III: Berlin – Adlershof

GEOHERMAL DISTRICT HEAT SUPPLY IN BERLIN

PROJEKTLEITUNG: ALI SAADAT





## Entwicklung eines geothermischen Wärmeversorgungskonzeptes für urbane Räume

### 1. Erkundung

- Passive seismische Exploration
- Bohrtechnische Erkundung

### 2. Charakterisierung

- (hydro-)geologisch-petrophysikalisch-geochemisch-mikrobiologisch/organ.

### 3. Modellierung

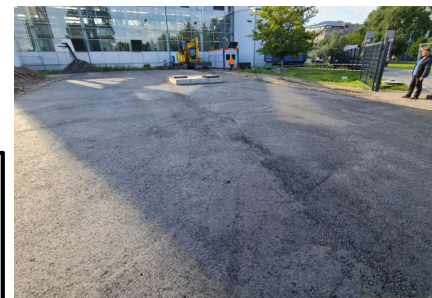
- Geologische Modellierung und Parametrisierung
- Lokale Untergrundmodellierung und Speicherdesign
- Gesamtmodell unter- und obertägige Anlagen und Wärmenetzeinbindung

Regionale Interpretation:  
Erhöhung der Planungssicherheit

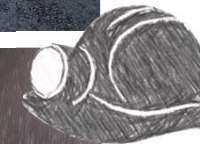
Tiefe 1m/2000m	Bohrart	Kernstrecke	Lithologie	Vorl. Stratigraphie	Bohrungsausbau
0	Schneckenbohrer und Eindrehen				
20				Quartär	
40					
60				Tertiär	
80					
100					
120	Eindrehen Hilfsrohtouren (Geolot) und Luftheben			Tertiär Rupelton	
140					
160					
180					
200				Tertiär?	

## Gt BTrKoe 1/2021 Bohrphase I (Quartär + Tertiär)

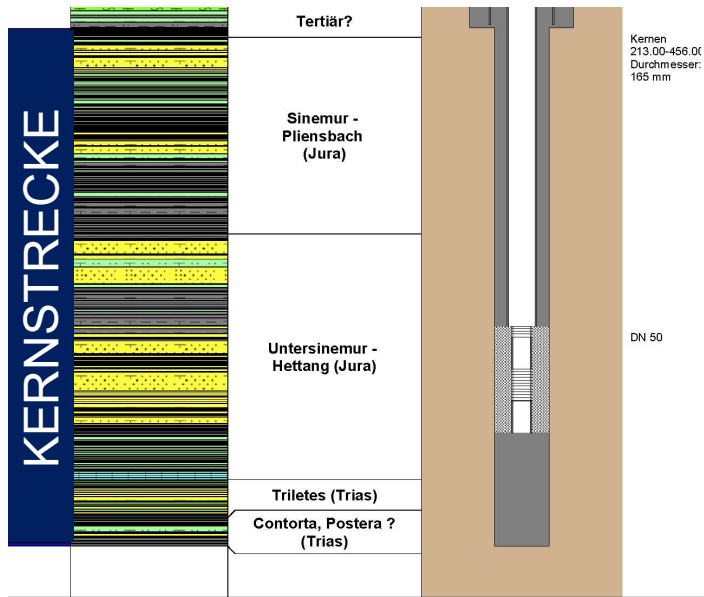
- Vorbereitung Bohrplatz (Asphaltarbeiten und Setzen Hilfsstandrohrtour)
- Lufthebeverfahren bis Basis Rupelton (über 100 m mächtig)
- Bohrlochmessung, Verrohrung, Zementation



Einrichtung Bohrplatz



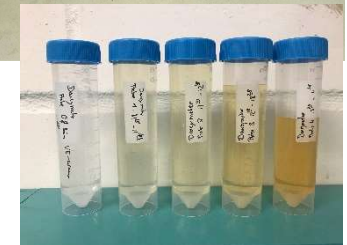
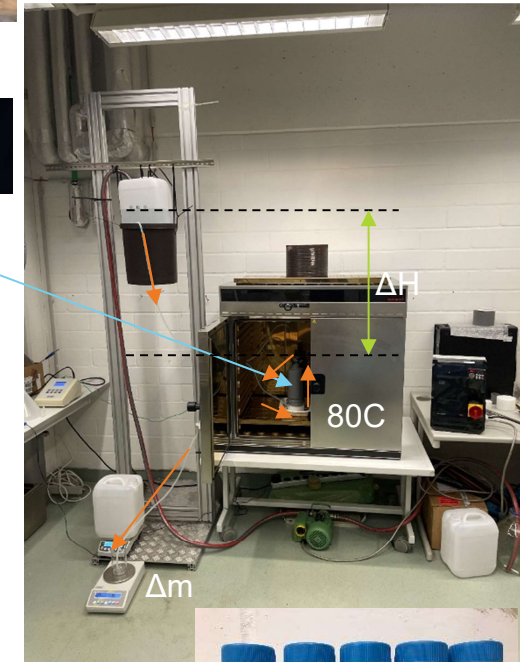
Luftheben



KM 64 Teufe: 386.15 - 387.15 m u GOK

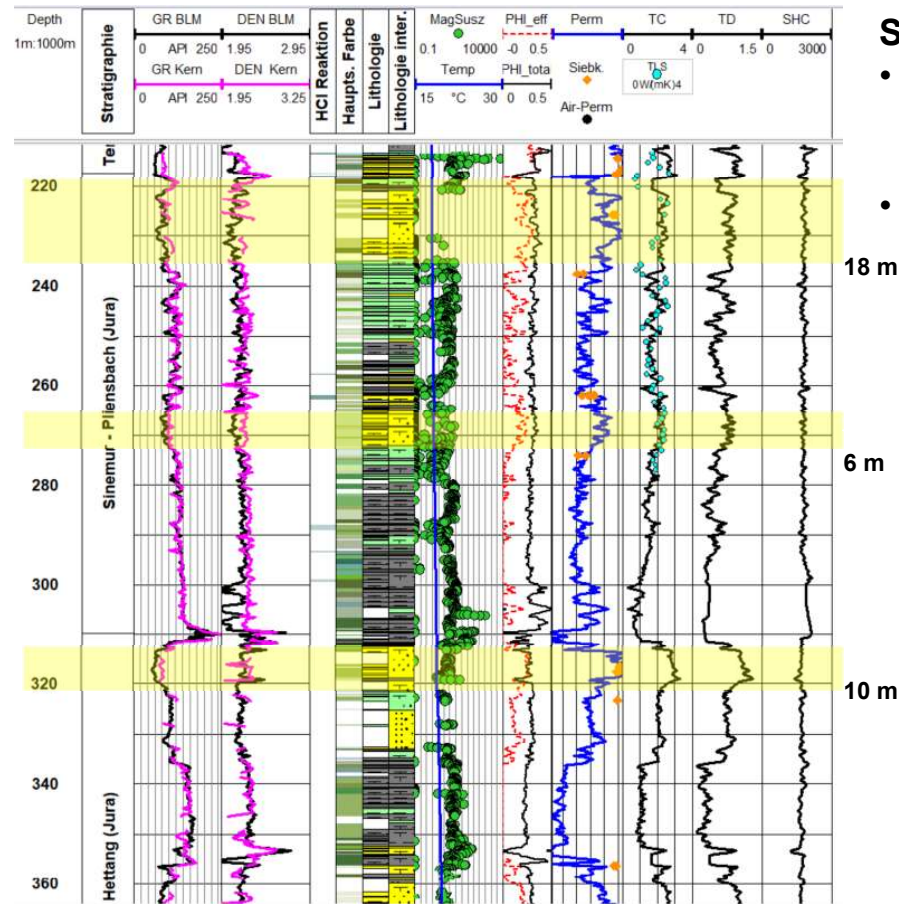


Bohrkern - Darcymeter



Bohrphase II (unterhalb Rupelton):

- Rotarybohren mit kontinuierlichem Kernen bis Erreichen EinstellungsHorizont:
  - tonige Ablagerungen Exter Formation (Rhätkeuper)
- Wissenschaftliches Kernuntersuchungsprogramm
  - thermisch-hydraulisch-chemische Wechselwirkungen

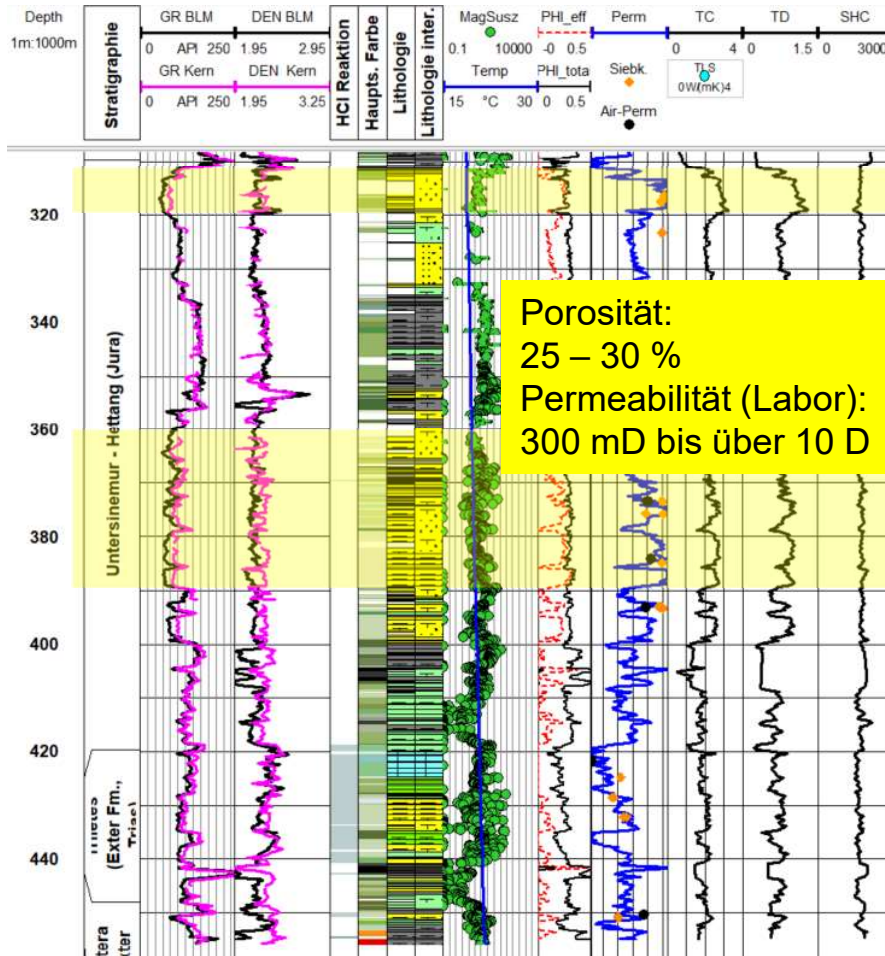


### Sinemur – Pliensbach:

- Ton- und Tonsiltsteine bis Sandsteine, z.T. in feiner Wechsellagerung
- Feinkörnige Sandsteinhorizonte:
  - Quarz (~ 85%)
  - Feldspäte (~ 10%)
  - Siderite (~ 5%)
  - Glimmer







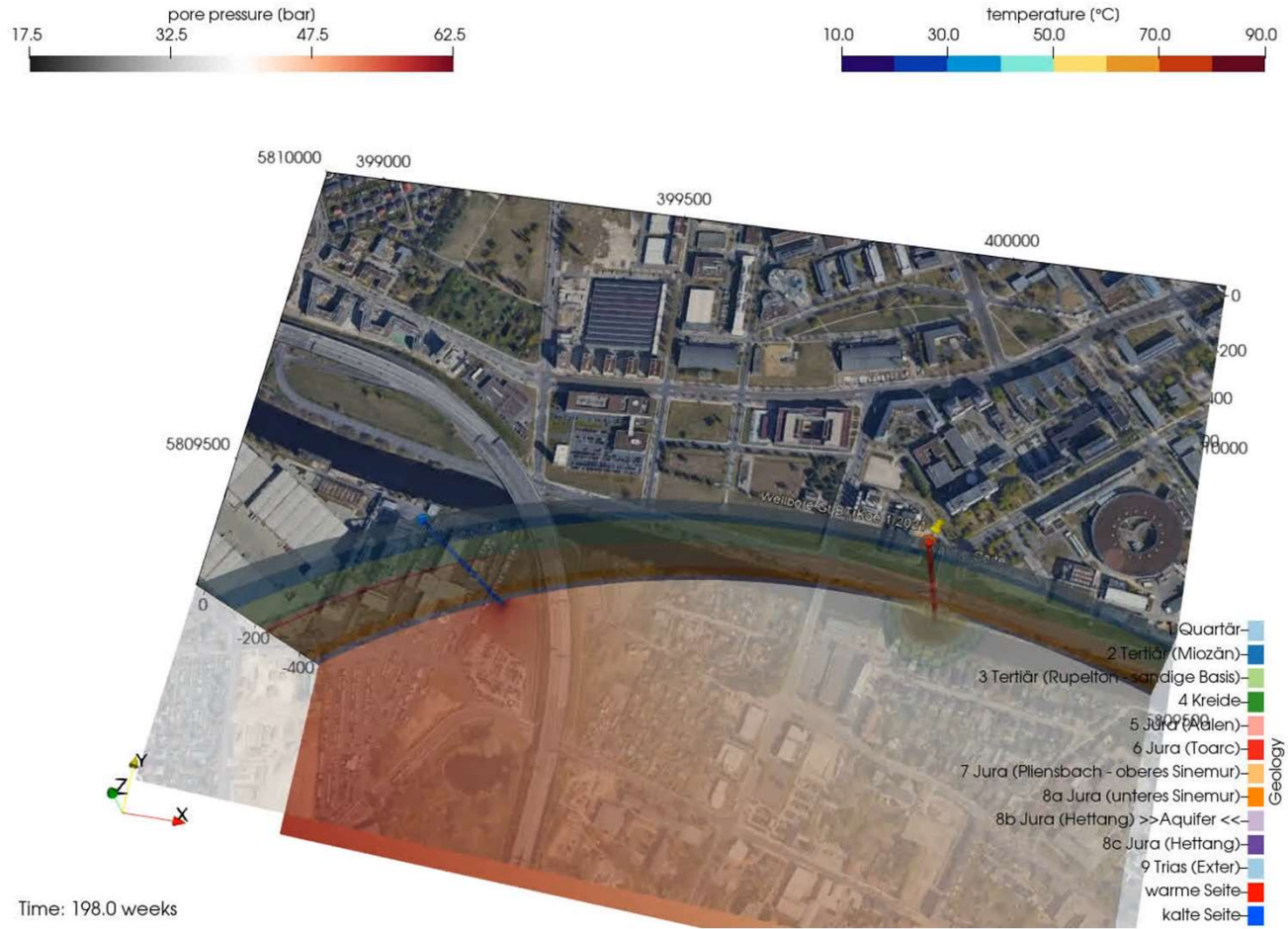
10 m

30 m



### Sinemur – Hettang:

- Ton- und Tonsiltsteine bis Sandsteine, z.T. in feiner Wechsellagerung
- Feinkörnige Sandsteine:
  - Quarz (~ 90%)
  - Feldspäte (~ 8%)
  - Akzess. (~ 5%): Glimmer, Kalzit, Siderit, Illit,,)



Berlin Adlershof – Erkundung des  
... ein Beitrag zur Wärmewende!

Untergrundes



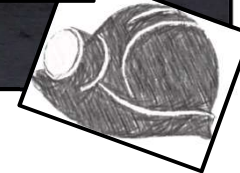
### Zusammenfassung

- jurassische Aquifere mit mehr als 5 m Mächtigkeit ?
- Sandsteinabfolge im Hettang ?
- Nutzporositäten und Durchlässigkeiten ausreichend ?

Mehrere

30 Meter

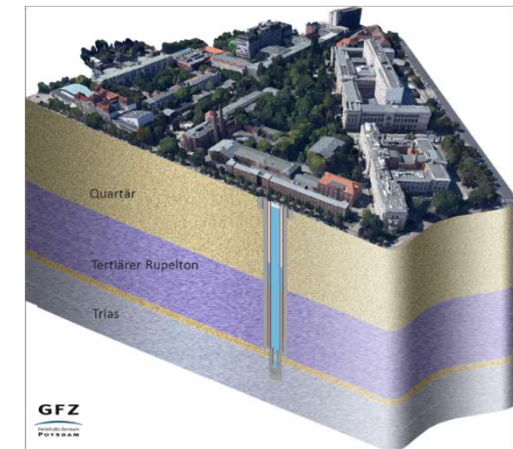
Ja



Ausblick: Testvorbereitungen und Standortentwicklung  
zur ATEs Dubletten - Nutzung (saisonal gespeicherte Energie:  
20 – 30 GWh)

# Fazit

- Mit jeder Bohrung wird es **weniger dunkel vor der Hacke** → Erhöhung der Planungssicherheit
- **Methoden zur Standortcharakterisierung und Prozessverständnis** (thermisch, hydraulisch, chemisch, mikrobiologisch) wurden entwickelt und angewandt
- **Wärme zum Speichern, Netzanbindung, Wärmekunden** sind wichtige Systemparameter
- Beitrag zur Gesamtsystembewertung mittels **Kriterienkataloges**



Ihre Fragen!