EGS technology: state of research and outlook

TECHNISCHE UNIVERSITÄT DARMSTADT

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H2020 DEEPEGS project: IDDP-2 well Reykjanes peninsular 4665 m

Geothermal technologies in Germany

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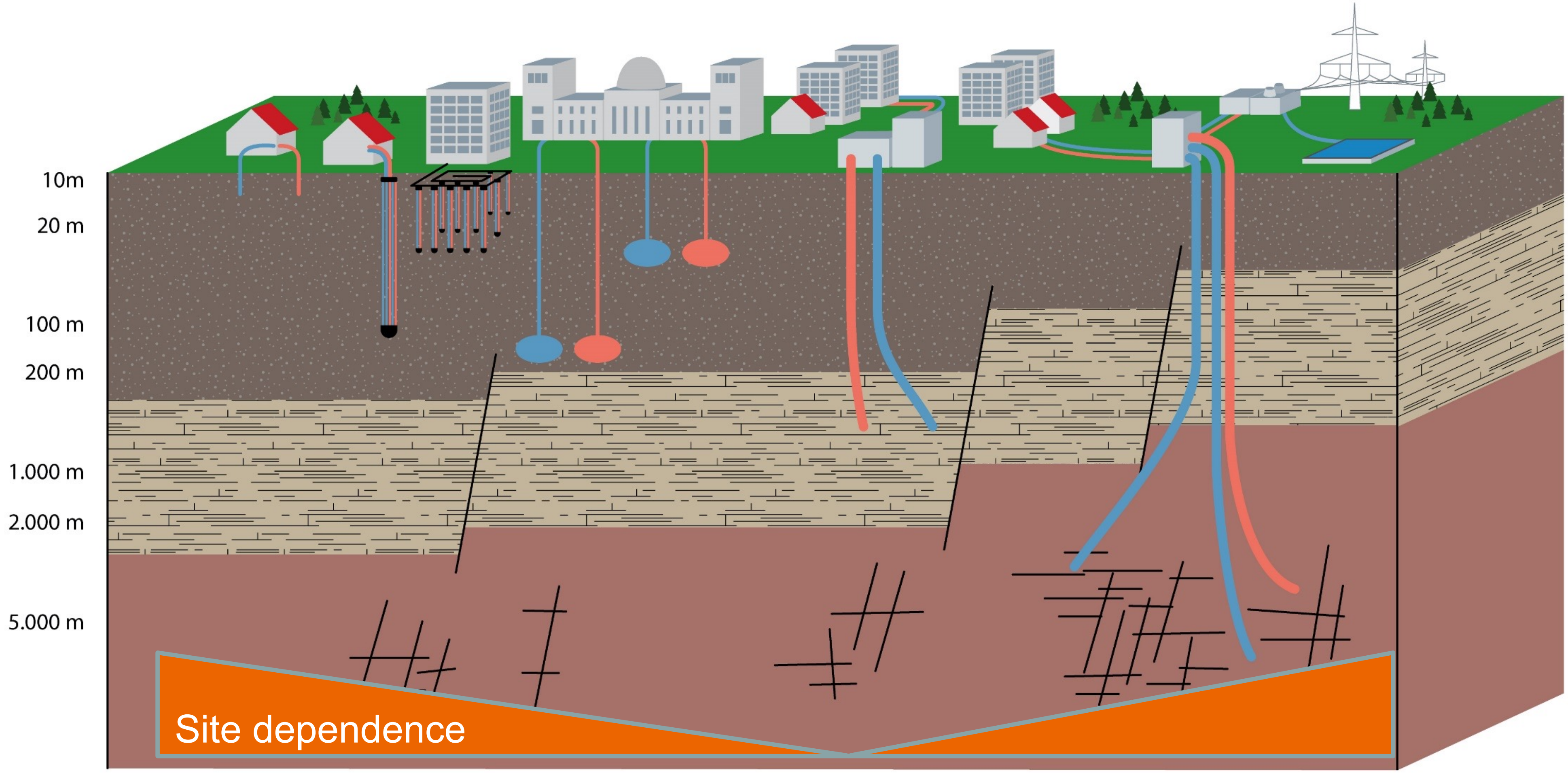
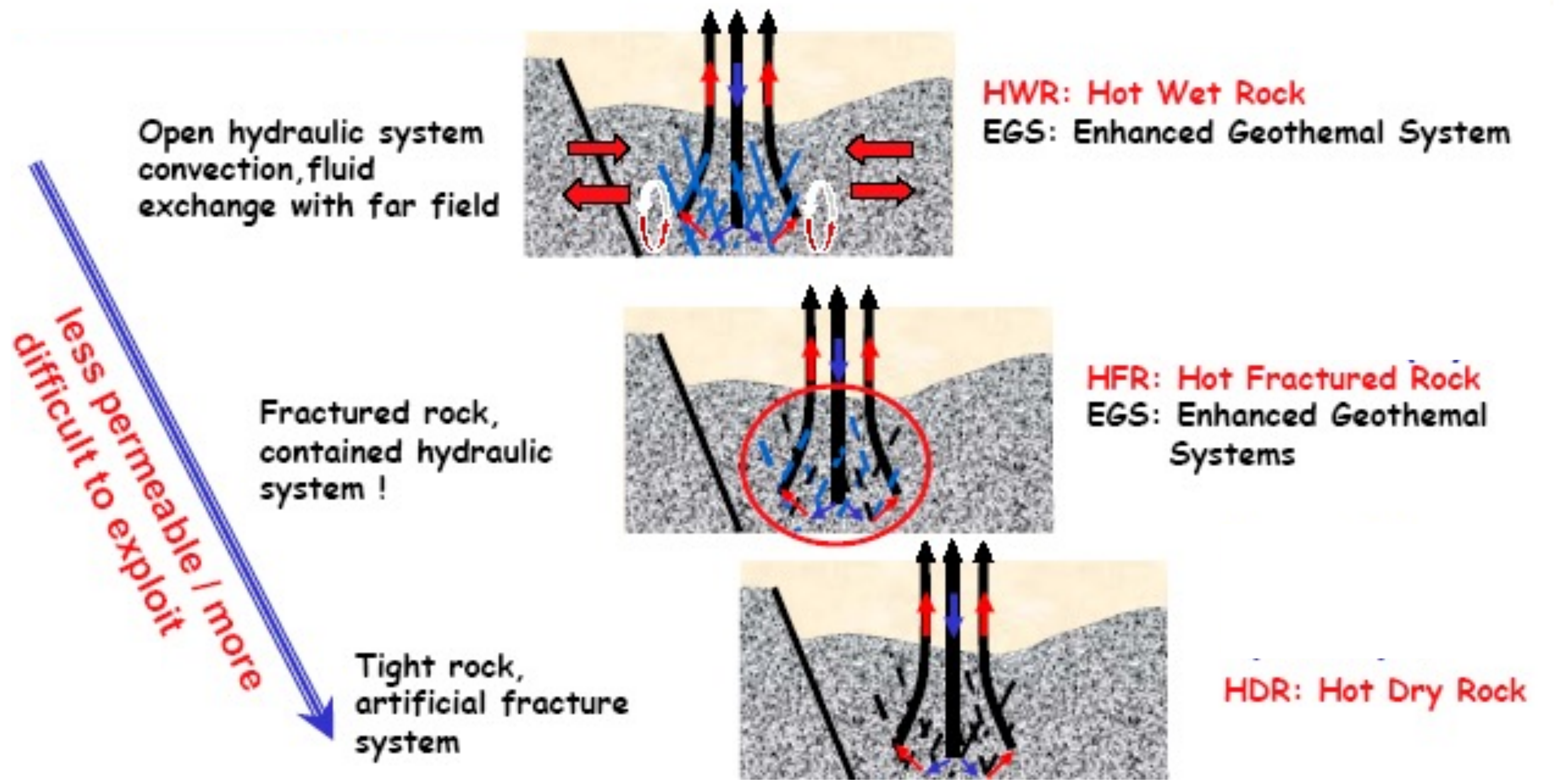


Decreasing permeability in crystalline rock



Baumgärtner, pers. comm.

EGS reservoir target parameters

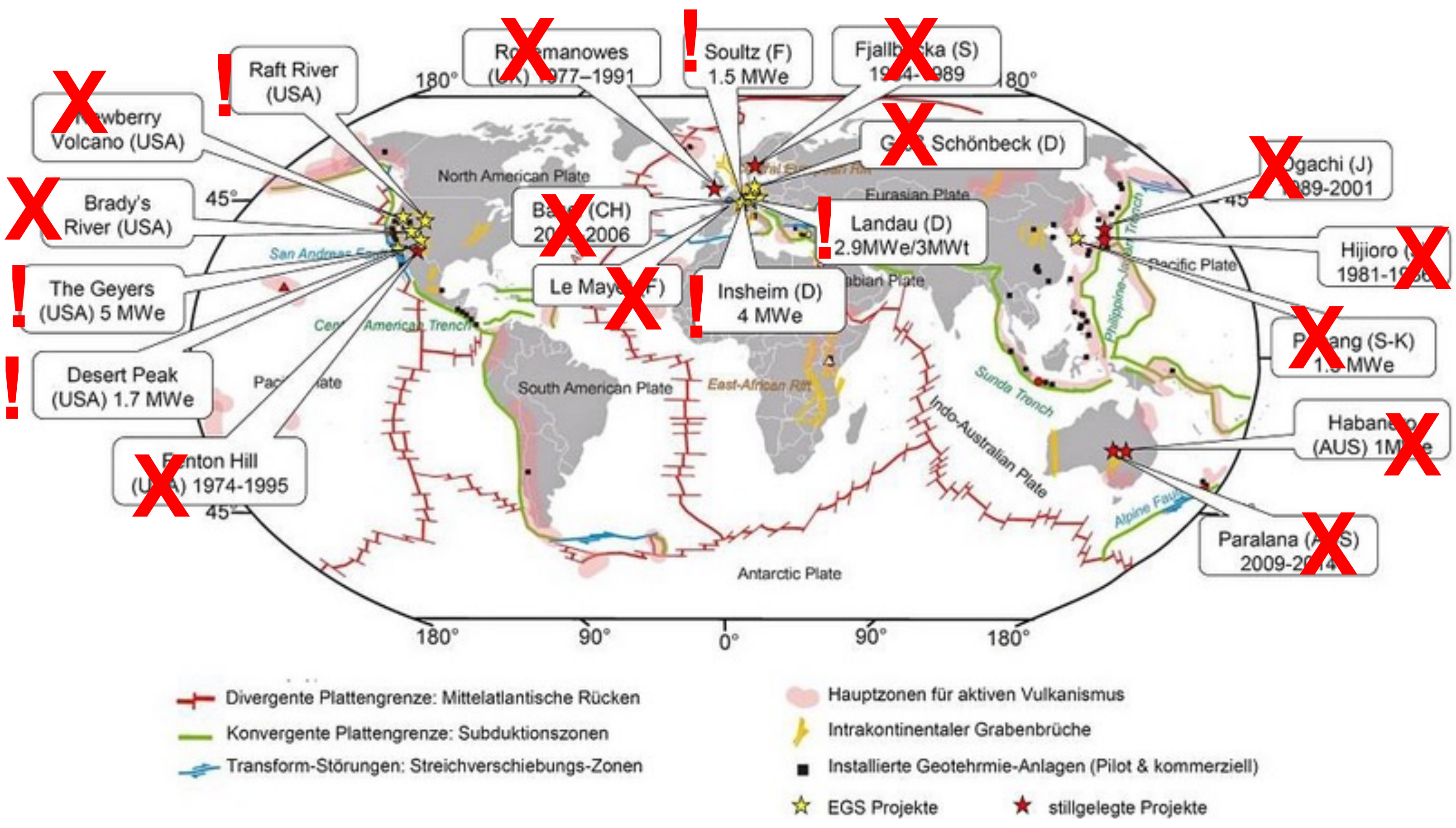
- Definition (Garnish, 2002):
  - Water flow rate: 50 -100 kg s-1
  - Wellhead fluid temperature: 150 - 200 °C
  - Effective heat exchange area: > 2 x 10^6 m^2
  - Rock volume: > 2 x 10^8 m^3
  - Impedance: 0.1 M Pa kg^{-1} s^{-1}
  - Water loss: < 10 %

- Typical systems
  - Doublet / Triplet
  - Temperature > 120°C
  - Depth > 3.5 km
  - Production: >2-5 MWe

- Subsurface heat exchanger:
  - Natural fractures
  - artificially enhanced through "hydraulic or chemical stimulation"

Global View on EGS

- History Background
  - Long learning curve
    - Since ~1974
  - Many different projects
    - volcanic
    - sedimentary
    - plutonic, ...
- Many failures
  - Overambitious
  - Starting projects
  - Strategic decisions...
- However:
  - Important successes

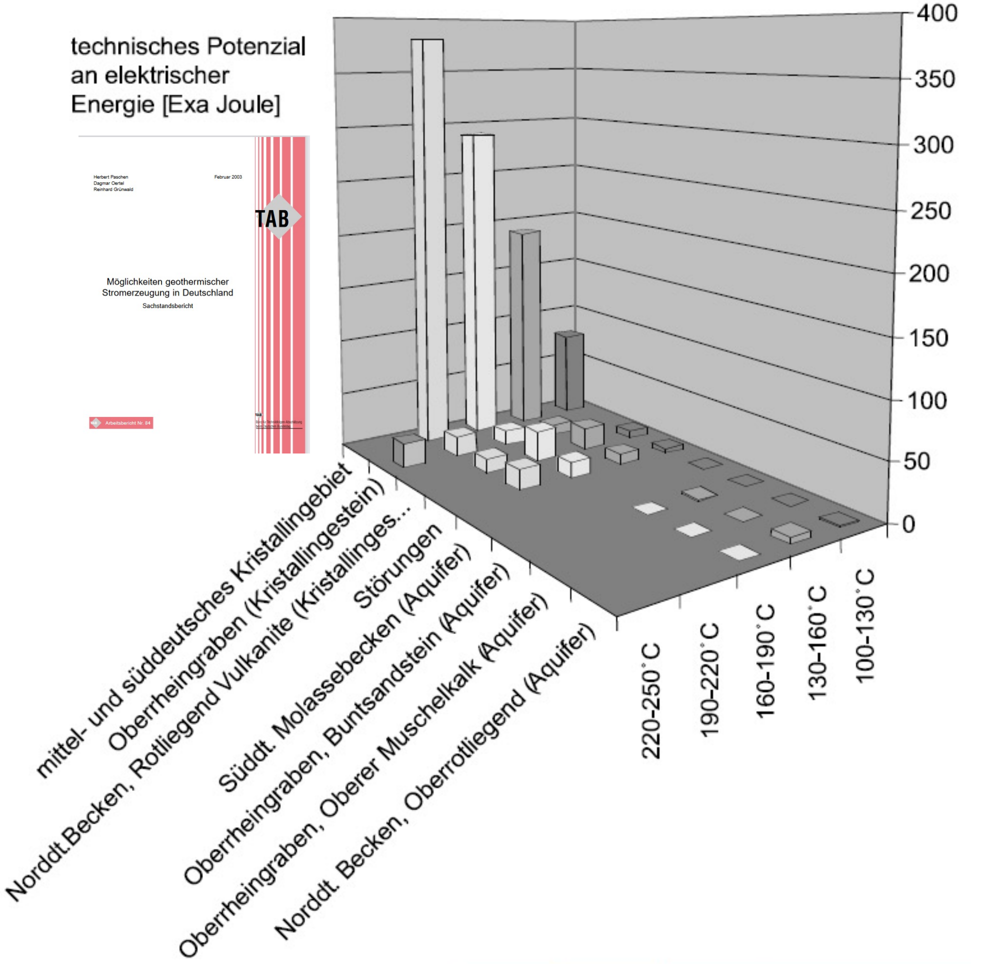


www.geothermie.de/

High EGS potential in the crystalline basement – Prototype Soultz-sous-Forêts

- EGS Soultz-sous-Forêts

Photo: Courtesy of GEIE



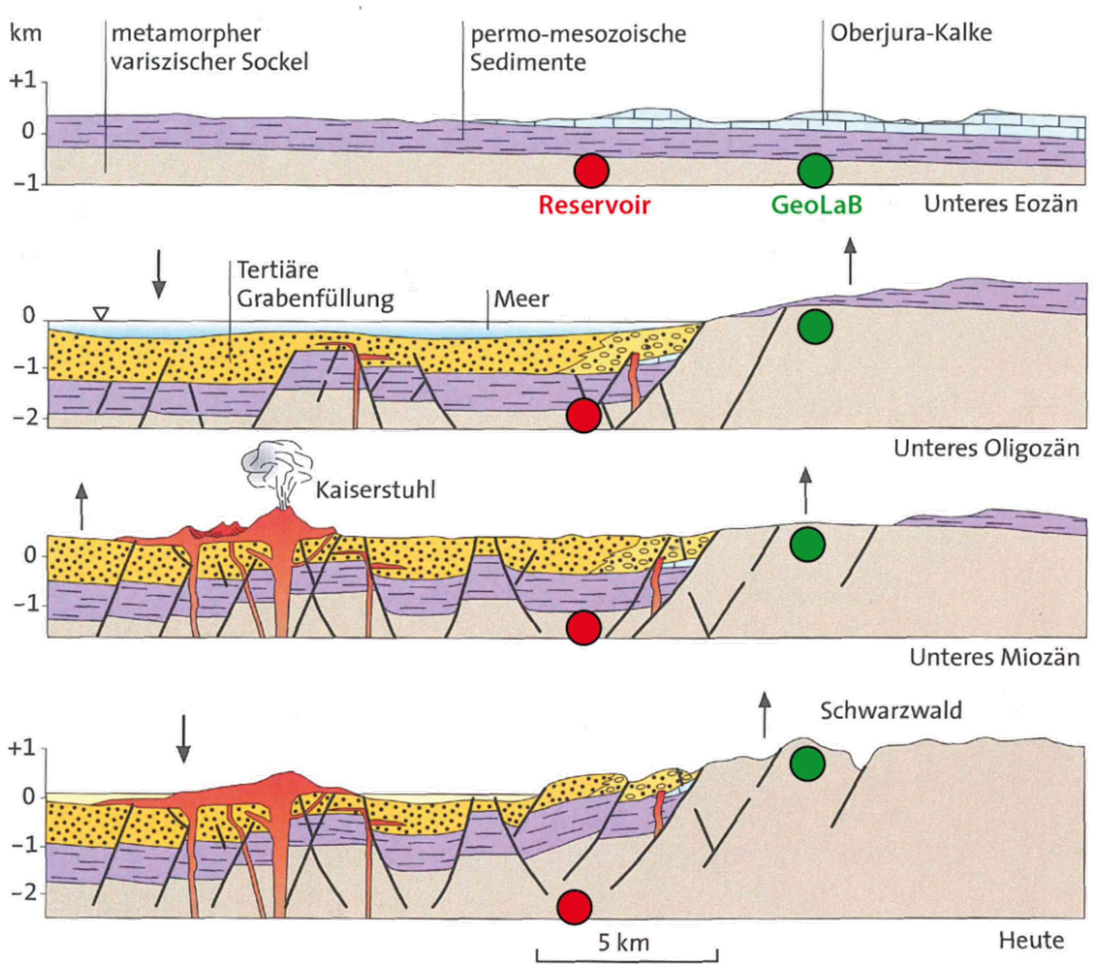
Development of crystalline basement in URG

55 Mio years

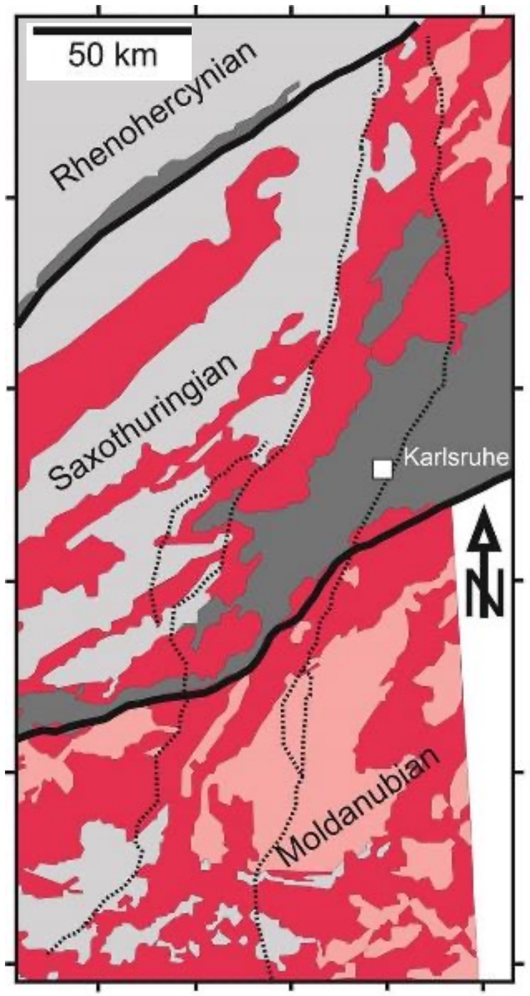
34 Mio years

23 Mio years

today



Meschede et al.

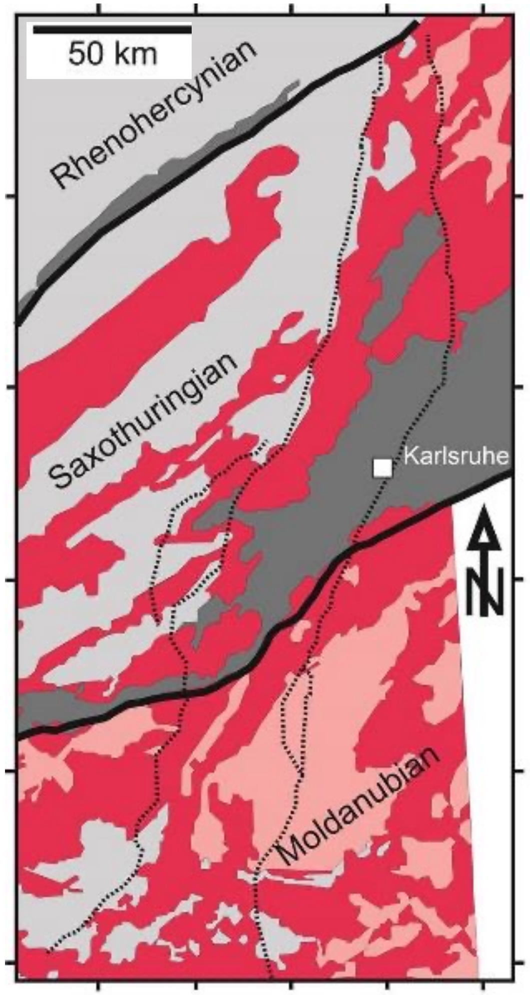


Grimmer et al., 2017

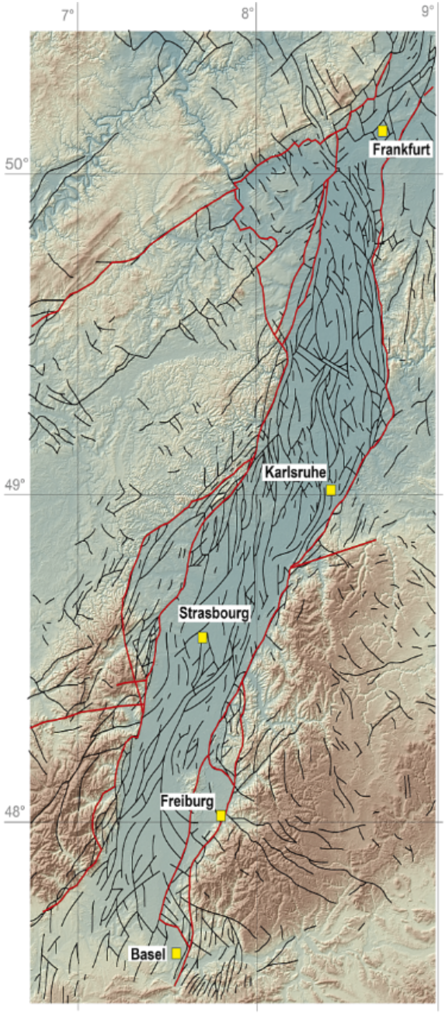
Crystalline basement in the German Upper Rhine Graben

- Active Tectonics
  - 350km N-S extension
  - 50km E-W extension

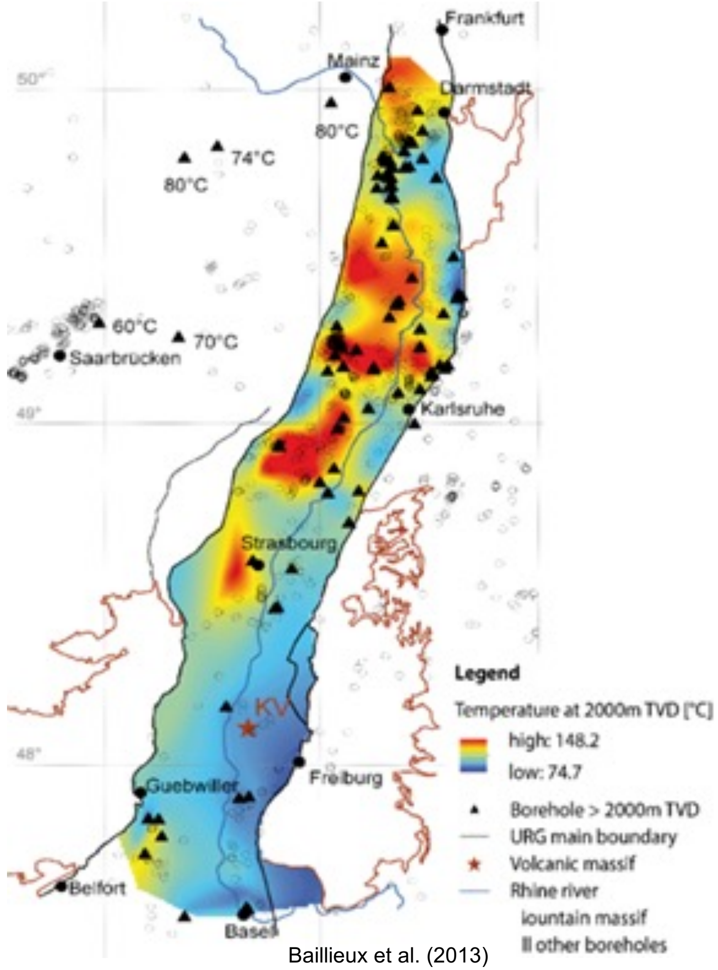
- EGS Systems
  - Soultz-sous-Forêts
  - Landau
  - Insheim
  - Rittershoffen



Grimmer et al. (2017)



Meixner et al. (pers.comm.)

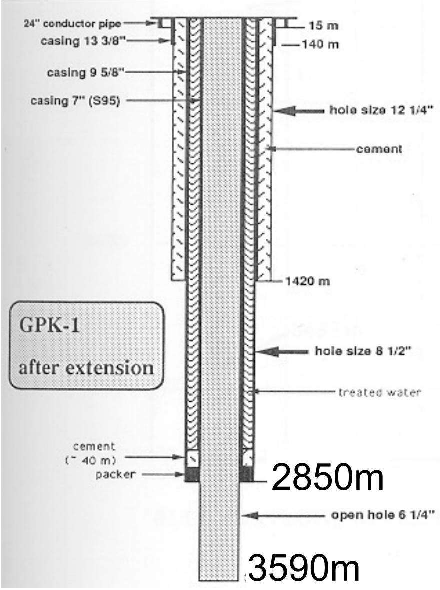


Baillieux et al. (2013)

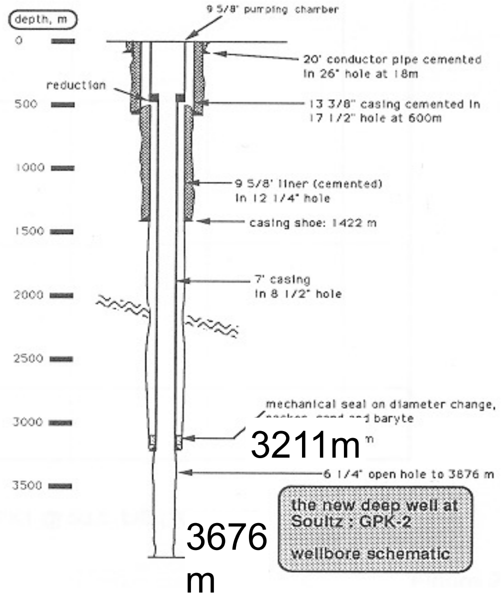
EGS key parameters

- Temperature
- **Hydraulic**
- **Stress Field**

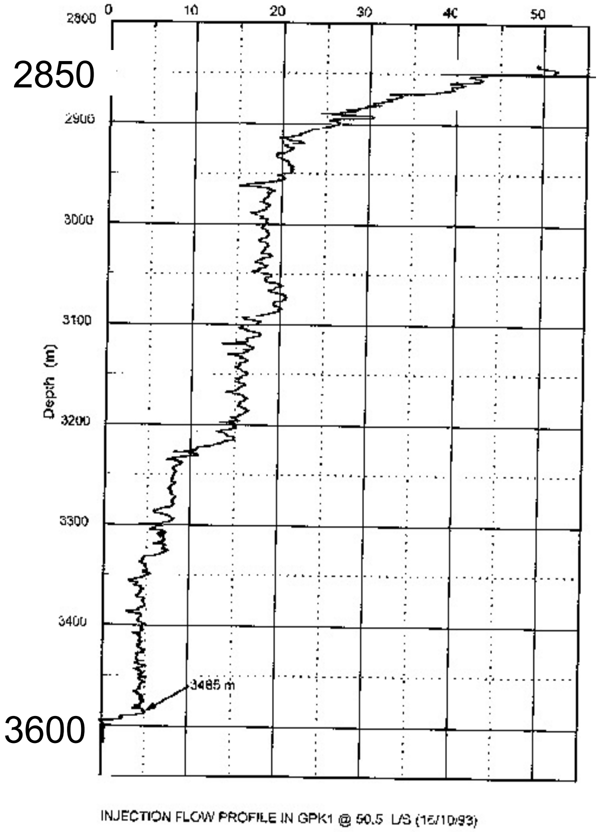
Borehole GPK1



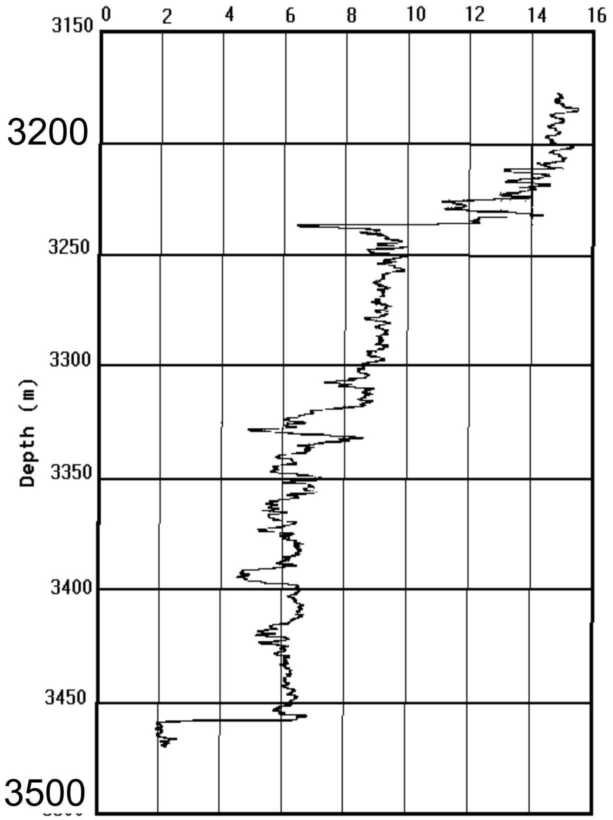
Borehole GPK2



Flowmeter log GPK1



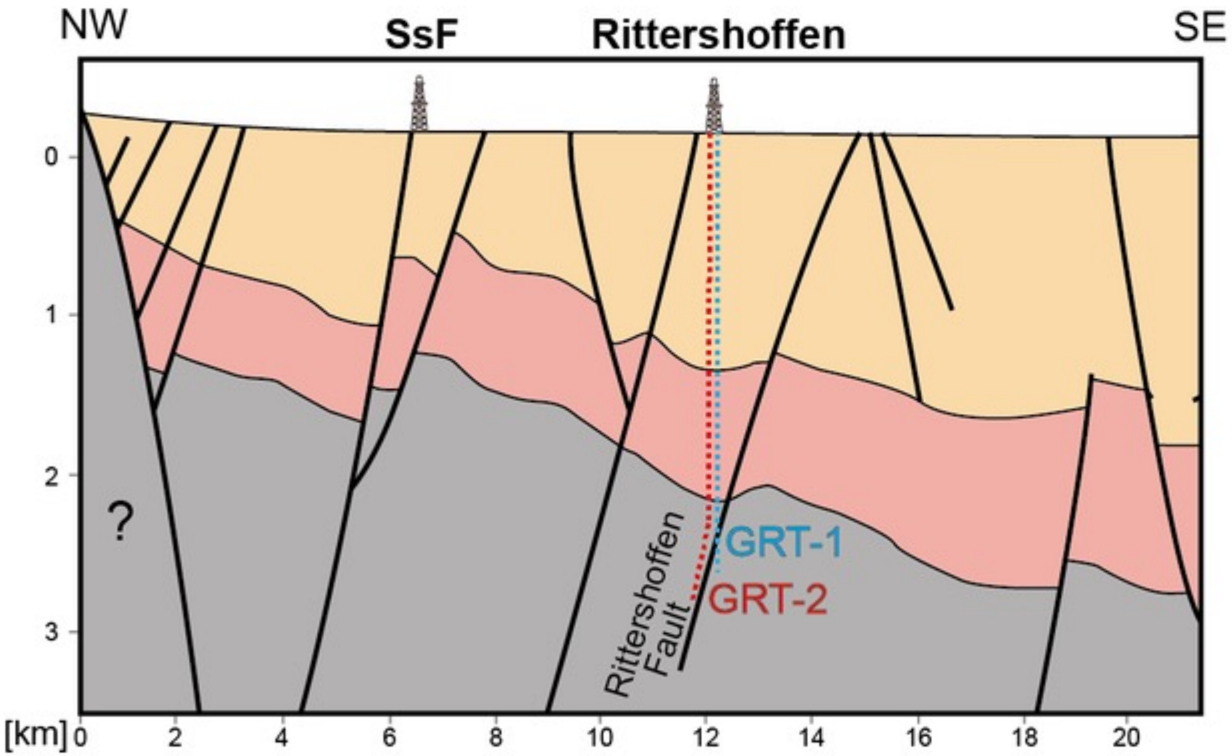
Flowmeter log GPK2



Courtesy of GEIE

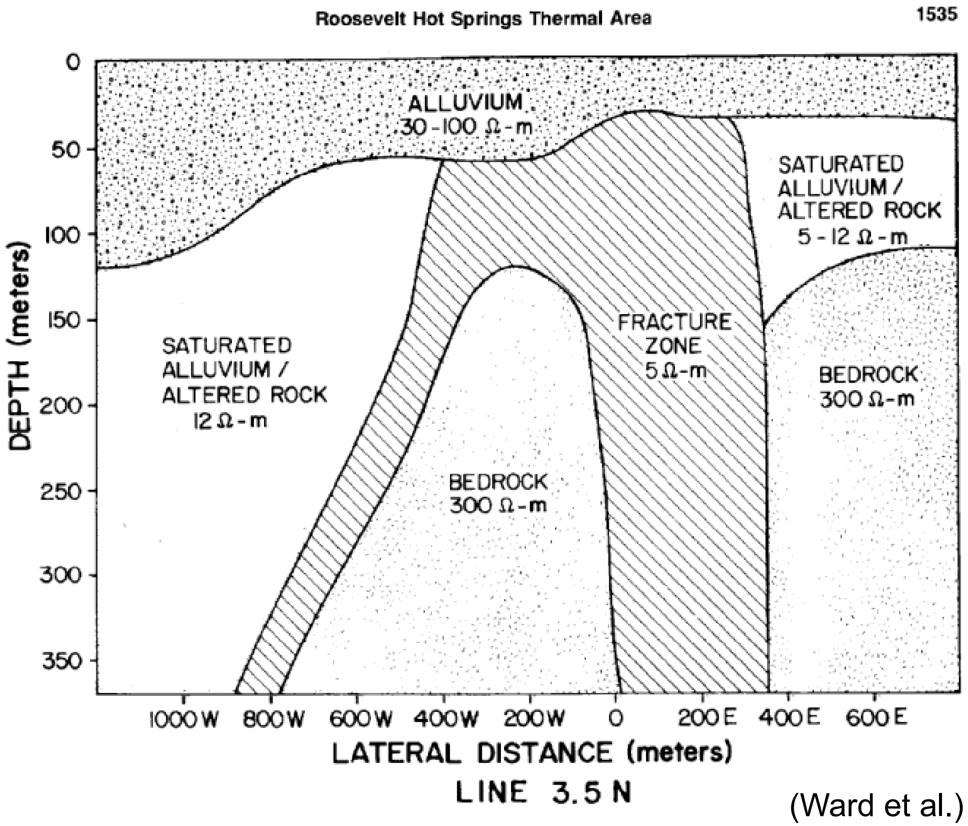
Similarity to Conventional Geothermal Geology

- Soultz-sous-Forêts (granitic)



(Vidal et al.)

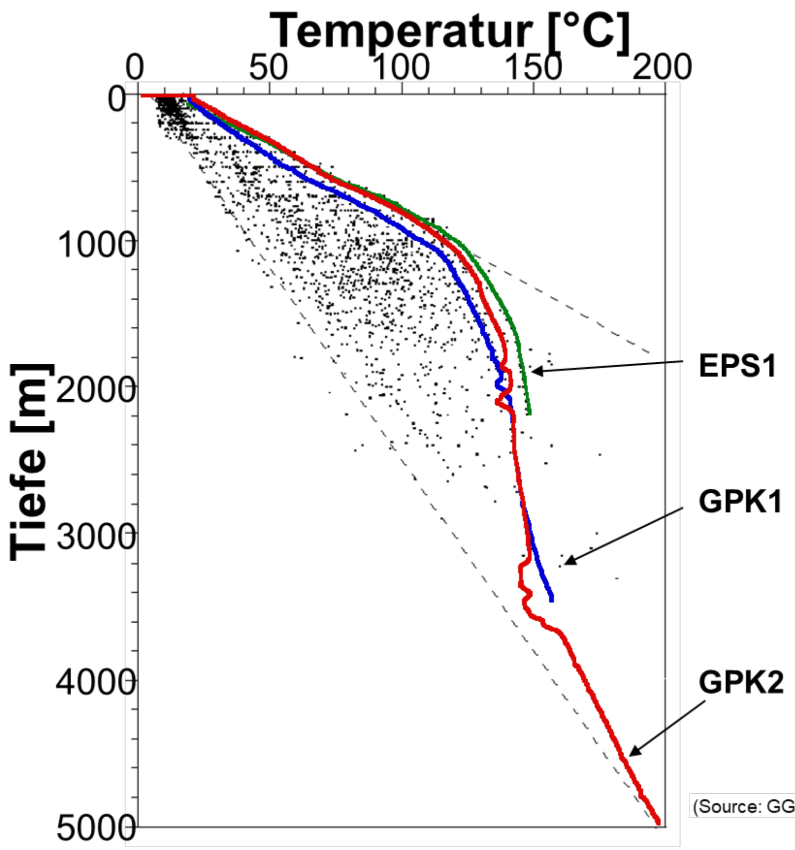
- Roosevelt Hot Springs (metamorphic)



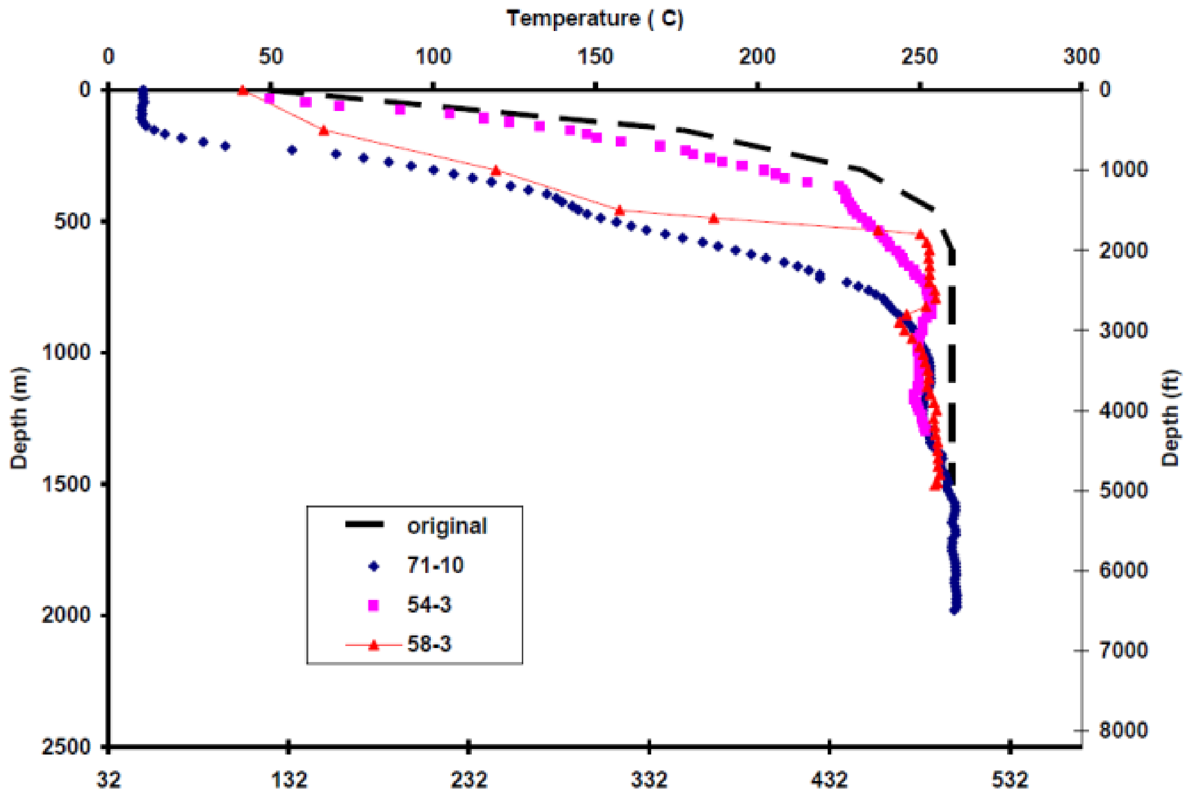
(Ward et al.)

Similarity to Conventional Geothermal Temperature profiles

- Soultz-sous-Forêts



- Roosevelt Hot Springs, Utah



(Source: Allis)

Heat transport in low-temperature systems

- Heat transport equation (without adiabatic effect)

$$\rho c_p \frac{\partial T}{\partial t} = \nabla (k \nabla T) + A - [\rho c_p]_f \, v_D \nabla T$$

EGS Soltz-sous-Forêts (state 2010)

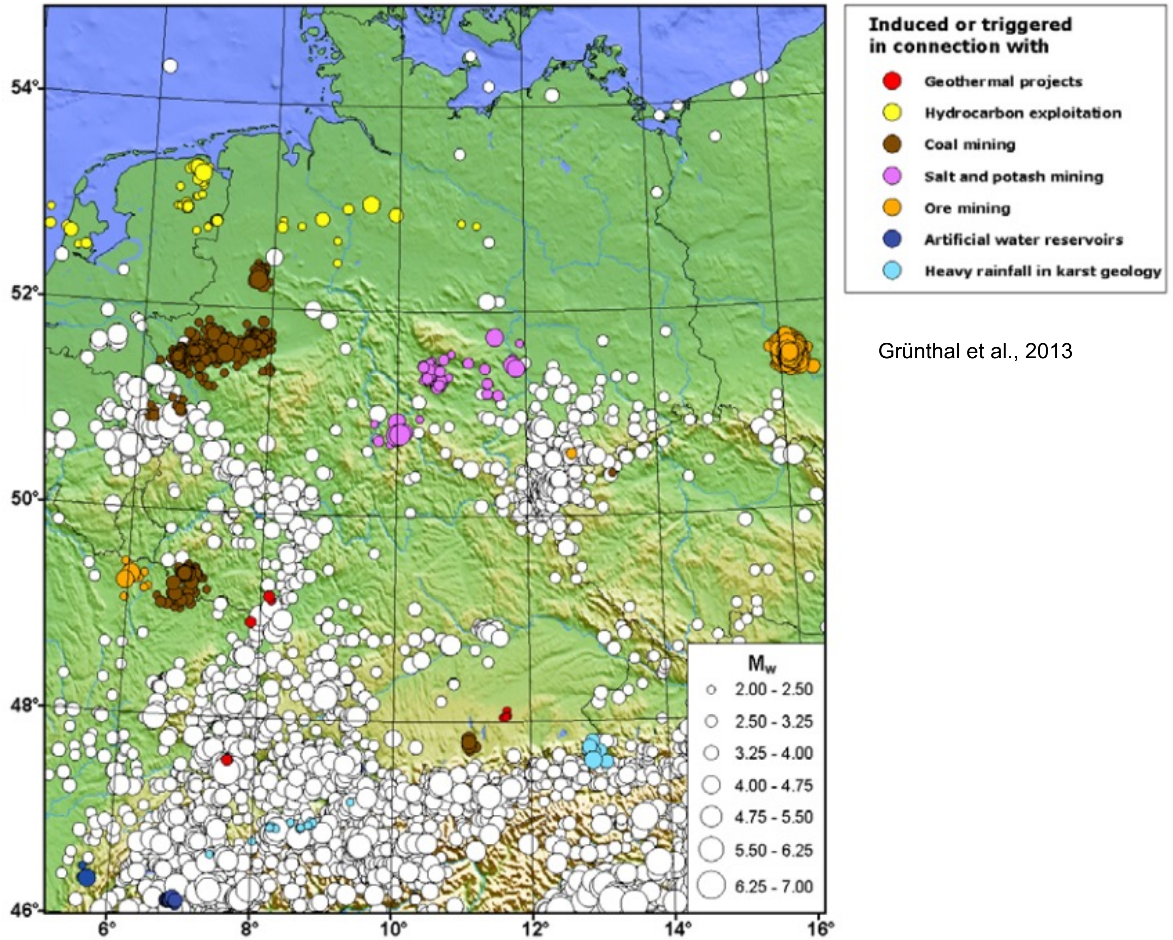
- Three reservoir created
  - 2000m
  - 3600 m: 2 wells in > 3km depth
  - 5000 m: 3 wells at 650m distance

- Parameters of plant:
  - Temperature 5km: 200ºC
  - Flow rate: up to 43 L/s
  - Installed capacity: 1.7 - 2.5 MW (ORC)
  - Natural brine: 100g/L, NaCl, pH~5

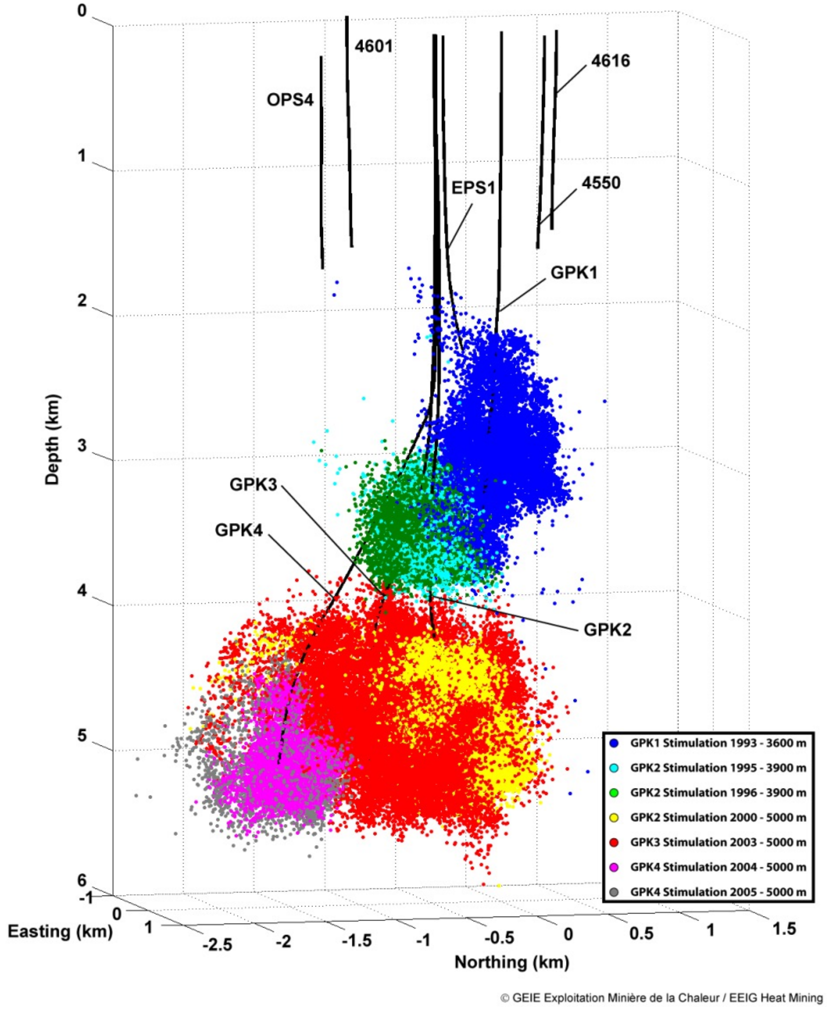
- Large reservoir with similar fluids

Photo: Courtesy of GEIE

Induced seismicity

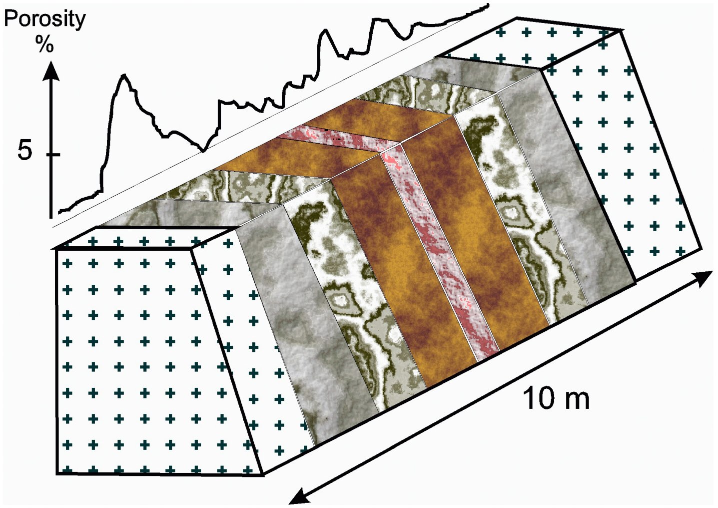


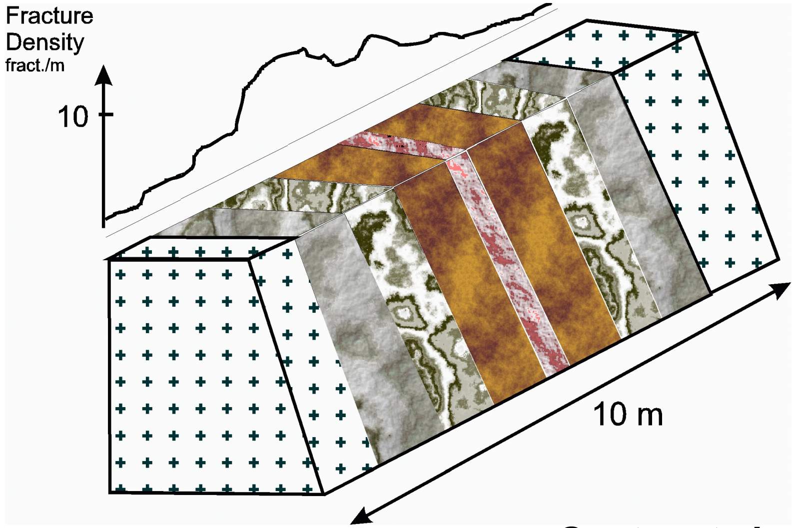
Grünthal et al., 2013



Hydrothermally altered & fractured zones in granite

- Fracture closely-spaced (cluster)
- Occurrence of « damage zone – core fault »
- Hydrothermal alteration (dissolution) and secondary deposition: quartz, illite, calcite
- Natural fluids: brines, 100g/l, low natural flow-rate

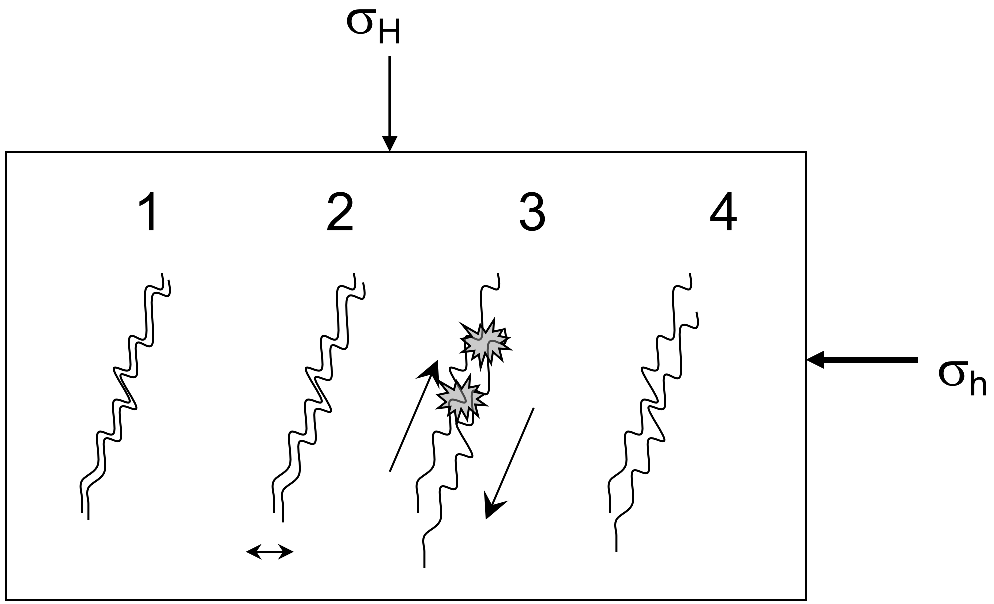




Genter et al., 2000

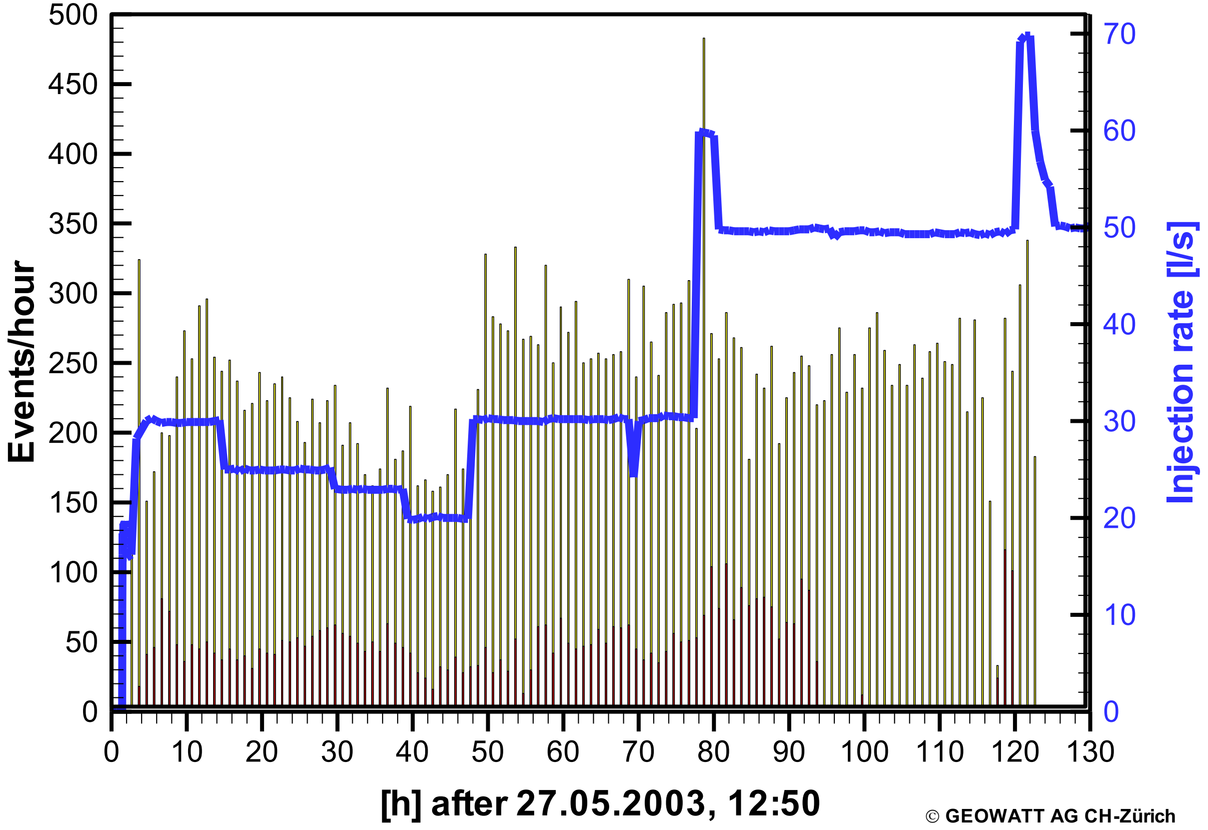
Enhancing hydraulic conductivity using hydraulic stimulation

1. Initial fracture in ambient stress field
2. Pressurizing => fracture compliance (normal opening)
3. Further pressurizing => shearing
4. remaining fracture aperture higher than initial



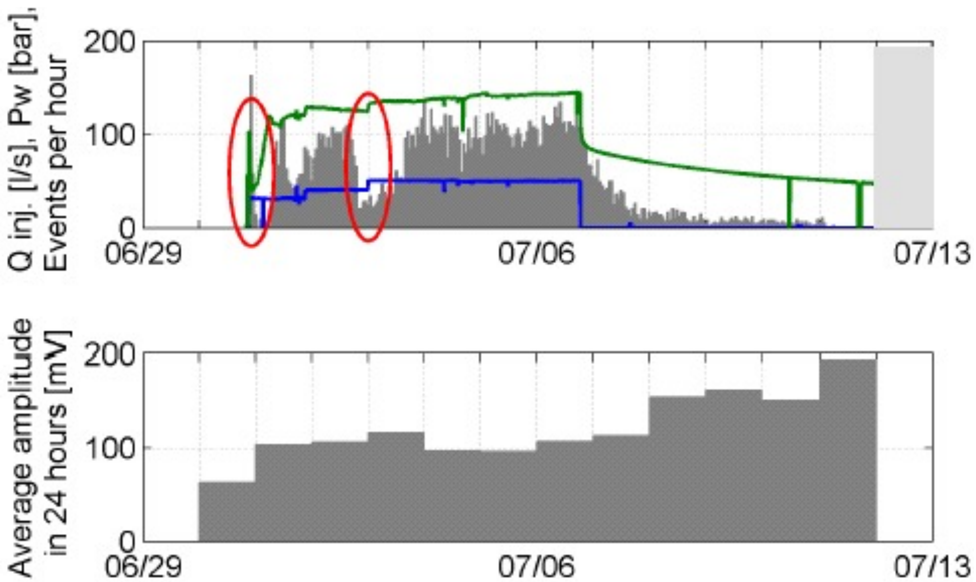
Reservoir engineering

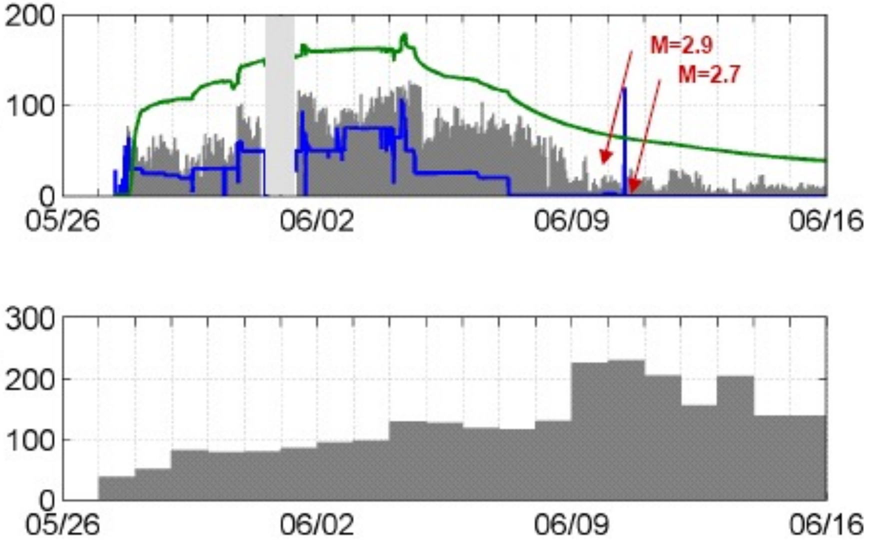
- Flow rate and seismic events



"Learning Curve" Soultz-sous-Forêts: Stimulation

- GPK2 in 2000
  - Volume 23'400 m³,
  - Well pressure up to 150 bar
  - Mag. M2.4 (Shut-In)
- GPK3 in 2003
  - Volume 37'500 m³,
  - well pressure up to 160 bar
  - Mag. M2.7 / 2.9 (Shut-In)





(Schindler et al., 2008)

Induced seismicity

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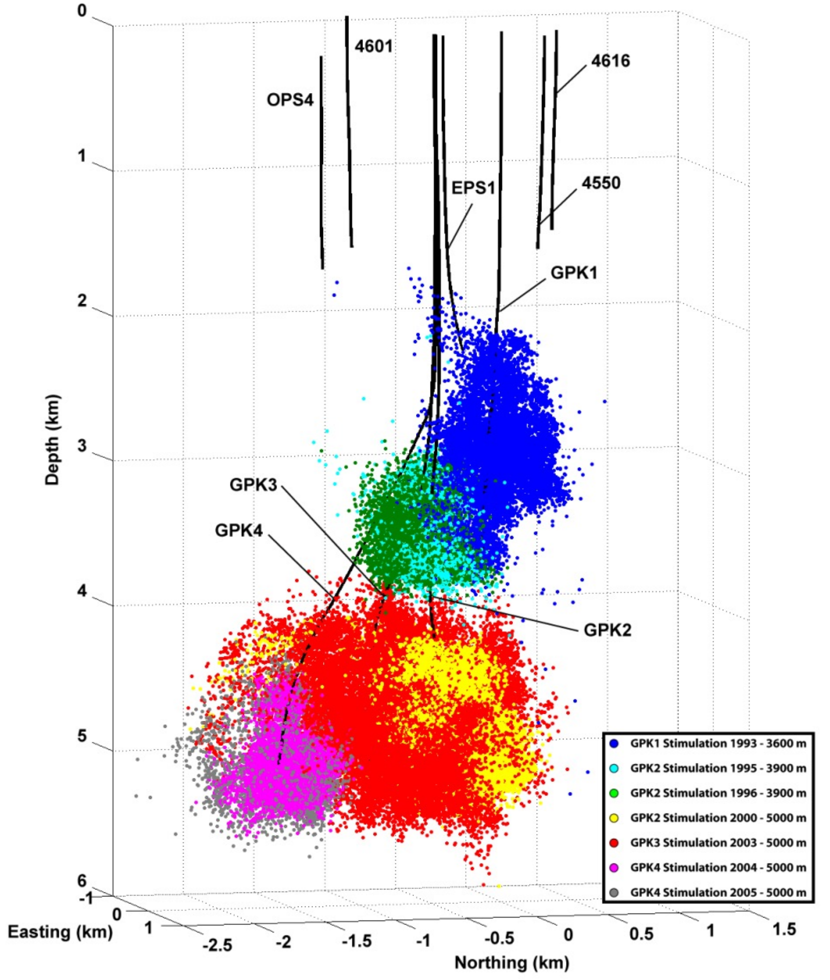
Dorbath et al., 2013	Injected volume	Maximum flow rate	Maximum over-pressure	Induced seismicity	Larger magnitude events
GPK2 (2000)	**~23’400 m^3**	**50 L/s**	**13 MPa**	**~14’000 (located)**	**75 (M≥1.8)** **1 x 2.6** **2 x 2.4**
GPK3 (2003)	**~34’000 m^3**	**50 L/s; 60 & 90 L/s focused stimulation**	**18 MPa**	**~22’000 (located)**	**43 (M≥1.8)** **1 x 2.9** **2 x 2.7**
GPK4 (2004)	**~9’300 m^3**	**45 L/s**	**17 MPa**	**~5’800 (located)**	**3 (M≥1.8)** **1 x 2.0**
GPK4 (2005)	**~12’300 m^3**	**45 L/s**	**19 MPa**	**~3’000 (located)**	**17 (M≥1.8)** **1 x 2.6** **1 x 2.3**

Courtesy of GEIE



© GEIE Exploitation Minière de la Chaleur / EEIG Heat Mining

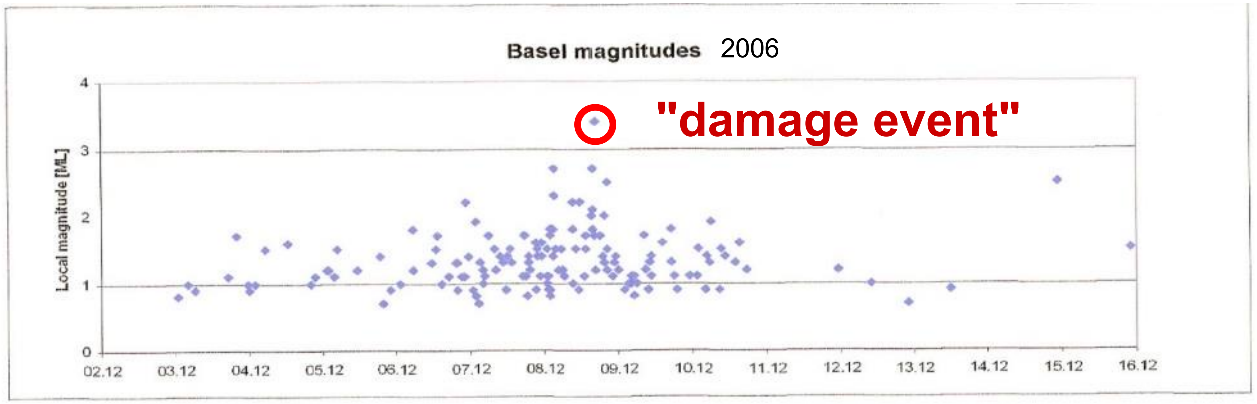
EGS Projects
DHM Project Basel – Operator "geopower AG"

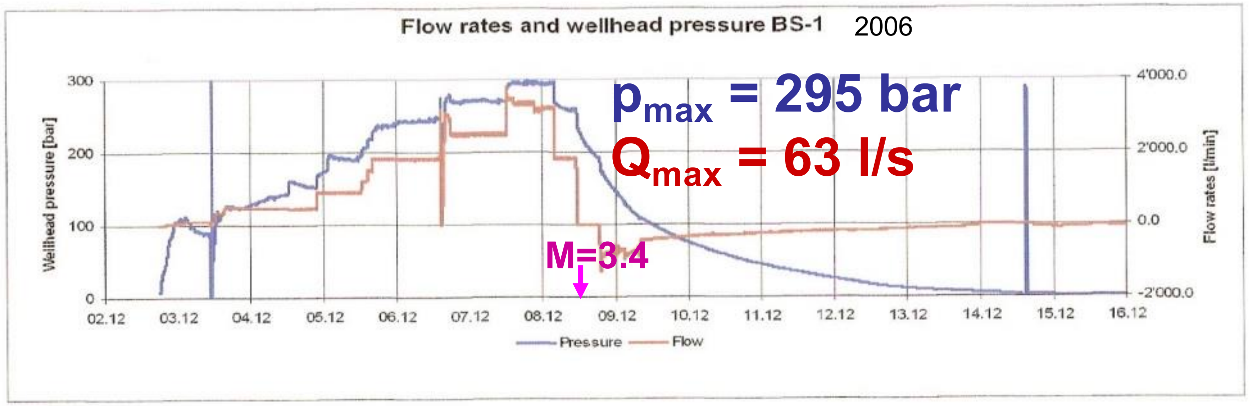
- Intention
  - Production of heat (district heating system) and power from 3-well system
- Reservoir:
  - granitic rock
  - no exploration
- Parameters of plant:
  - Depth 5000 m
  - Temperature. 200ºC
  - Installed capacity 6 MW_e & 17 MW_{th} (planned)
- Activities:
  - 15 Mai 2006 start of drilling operations
  - October 2006 1st well completed
  - December 2006 Major stimulation
  - 8 Dec 2006 Earthquake Mag 3.4 / 2.4, subsequent Mag 3.1/3.2/3.3/2.9 → project on standby
  - 12 Dec 2009 → project suspended

Photo:Geopower, 2006

EGS Projects
DHM Basel - Induced (Man-made) Seismicity (MMS)

- Low transmissivity
  - High hydraulic pressure level
  - High hydraulic energy
  - High Seismicity



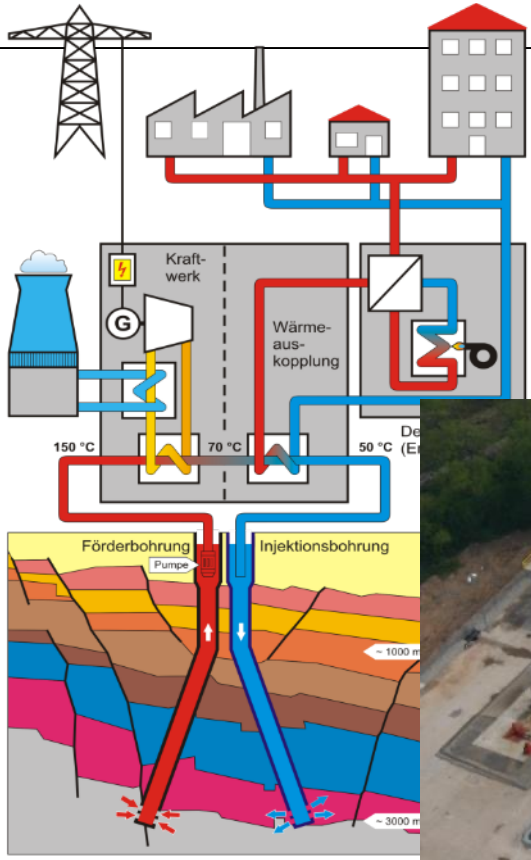


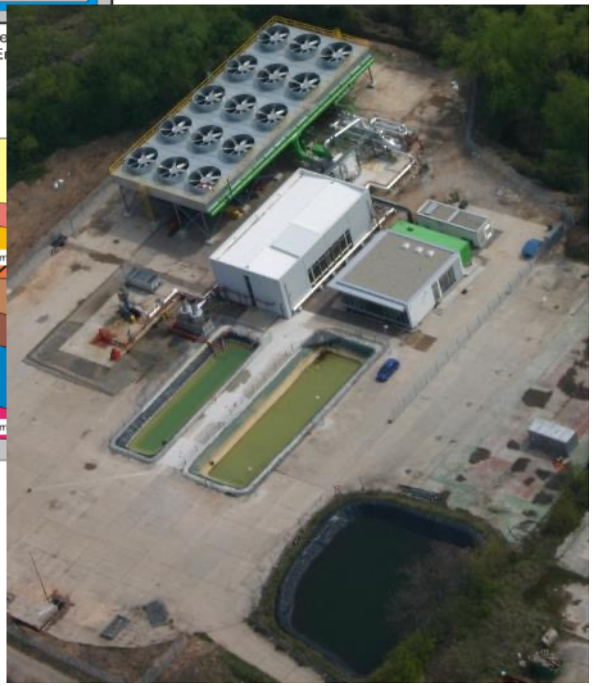
- Hypocenter in 4-5 km depth.
  - After 1 month, approx. 23% of injected fluids were recovered

Geopower 2007

EGS Projects
Landau

- Operator: geox (Geysir Eur., Energie SW)
- Reservoir:
  - Permeable fault zones in Muschelkalk, Buntsandstein and Granite.
  - Multi-horizon exploration
- Parameters of plant:
  - depth   3000 m
  - temp.   160ºC
  - flowrate   50-80 l/s
  - capacity   3 MW (ORC)
- Activities:
  - 2006   two wells / Successful Testing
  - 2007   Installation of plant / cooling unit
  - 2008   Start Operation
  - 2009   Earthquake Mag 2.7 / 2.4
→ reduced operation
  - 2014   Major Leakage in upper casing
→ swelling @ surface; groundwater





Source: Geox, 2009
BINE, 2009,
engine, 2006

EGS Projects
Insheim

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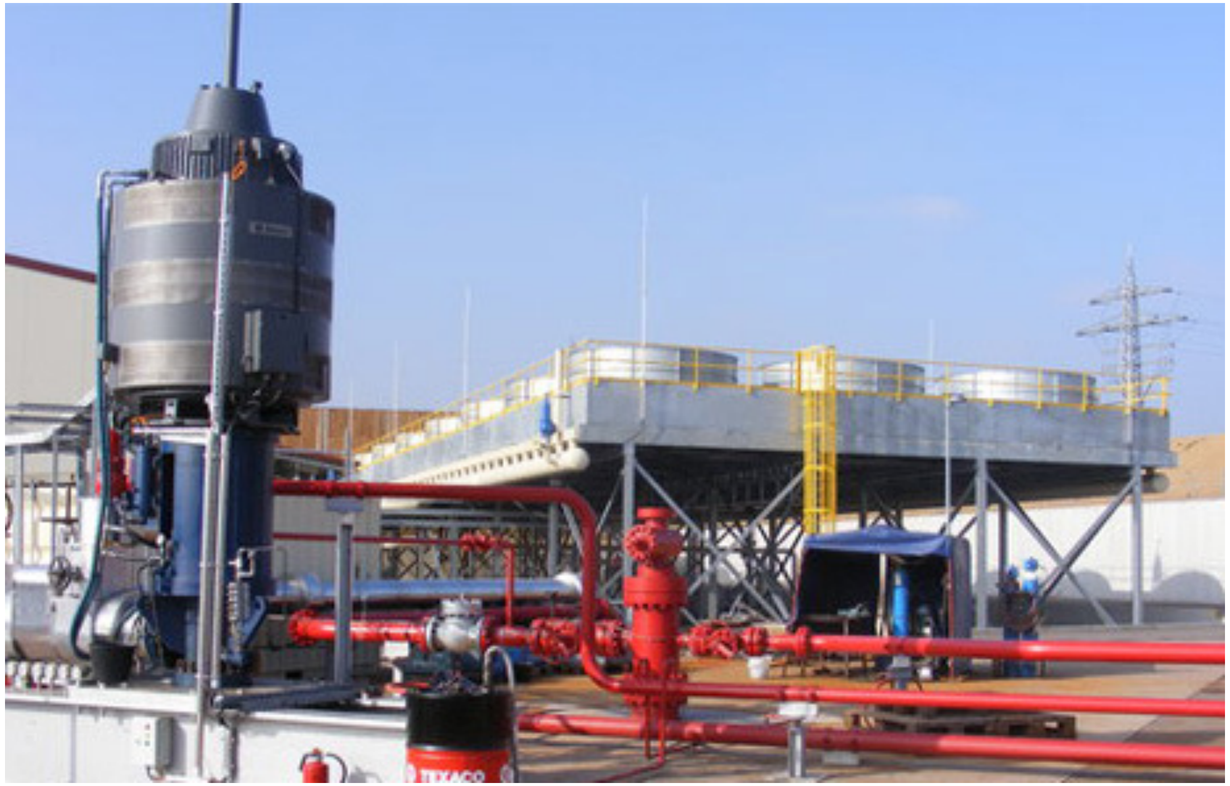
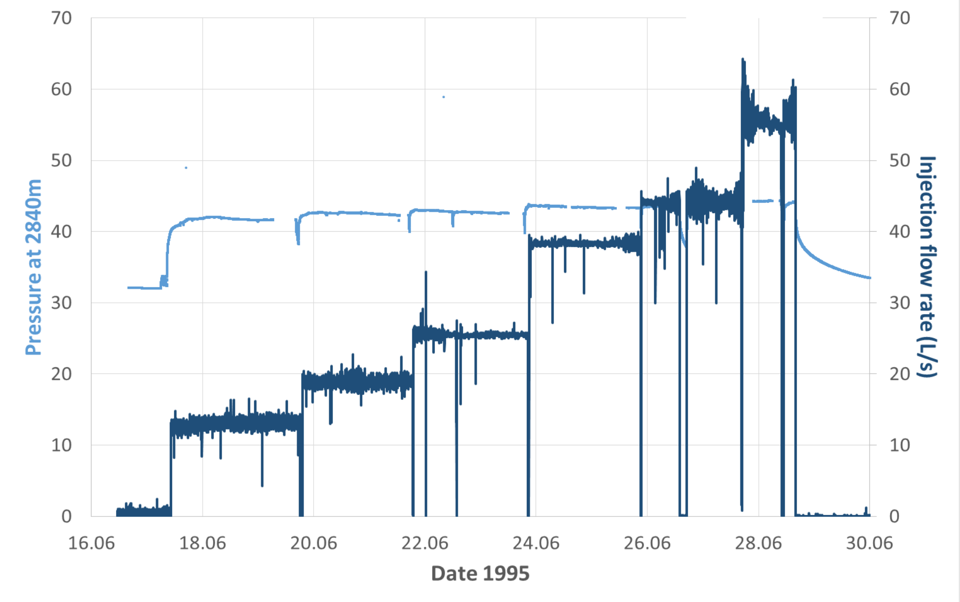
- Operator: Vulcan Energy Resources
- Reservoir:
  - Permeable fault zones in Muschelkalk, Buntsandstein and Granite.
  - Multi-horizon exploration
- Parameters of plant:
  - depth 3600 m
  - temp. 165ºC
  - flowrate 50-80 l/s
  - capacity 4.8 MW (ORC)
- Activities:
  - 2008 First well / Testing
  - 2009 Second well / Testing
  - 2010 Circulation
  - 2010 Side track
  - 2012 Start Operation
  - 2013 minor Earthquake Mag 2.1
    Slow increase of pressure/flow

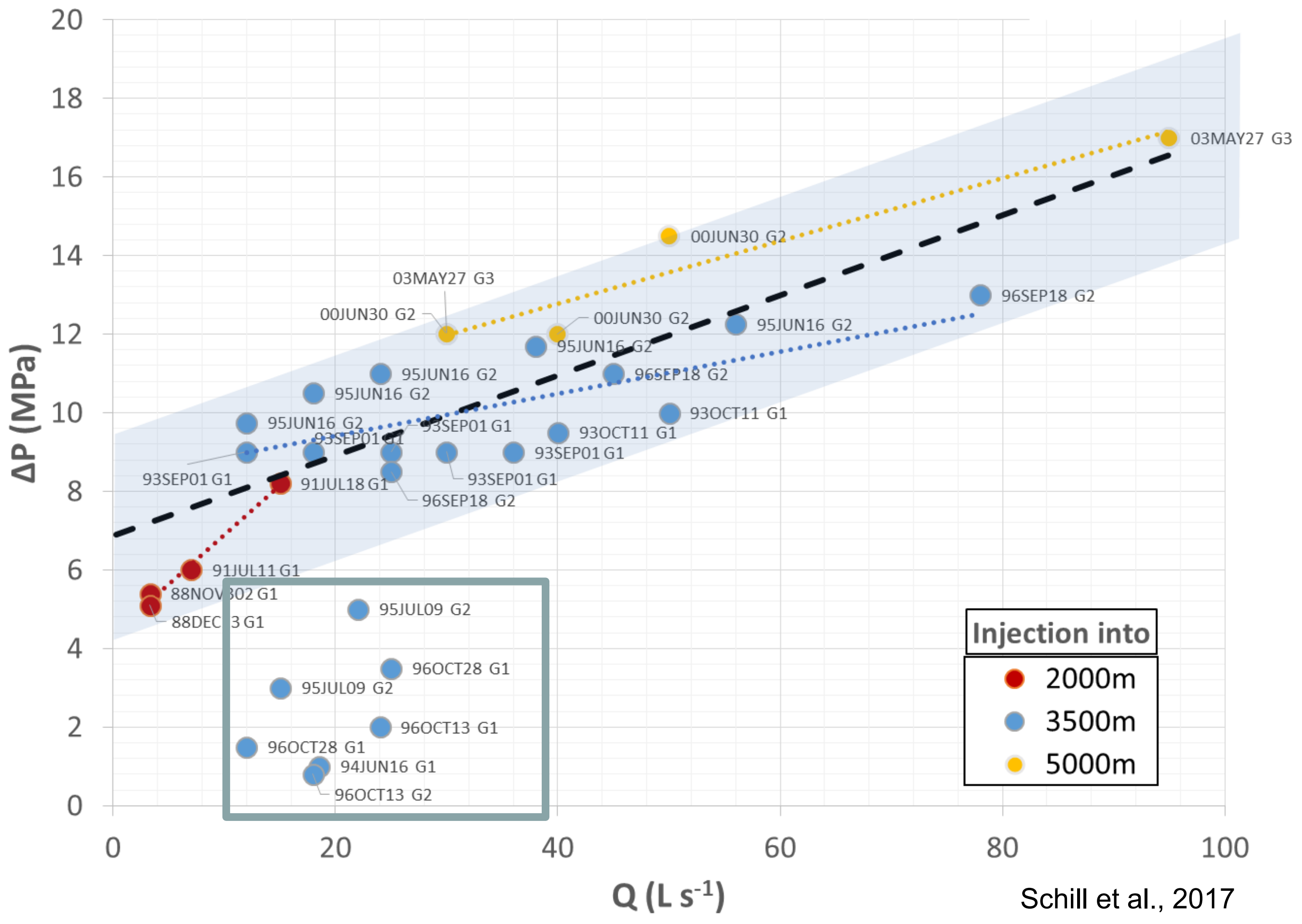


http://www.geothermie-insheim.de

Learning curve
Mitigation of induced seismicity

- Injection test with low pressure changes ΔP

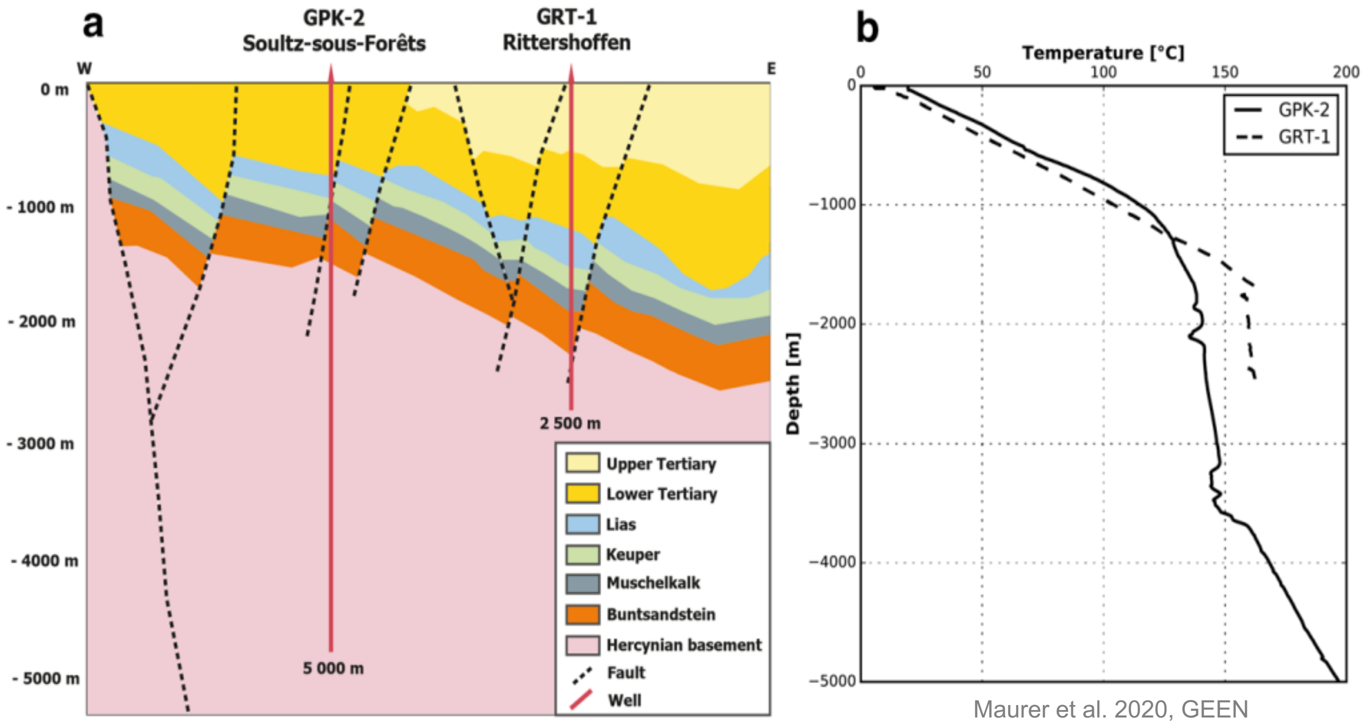




Schill et al., 2017

ECOGI Project
Rittershoffen

- Doublet GRT-1 and GRT-2
- Reservoir at ~2.5 km depth
  - Triassic sandstone / Paleozoic granite
  - Thickness is ~500 m
- Production since 2016
  - Drying of starch
  - for bio-refinery at 15 km distance
  - 24 MWth heat,
  - (70 L/s, 170°C)



Maurer et al. 2020, GEEN

ECOGI Project
Rittershoffen

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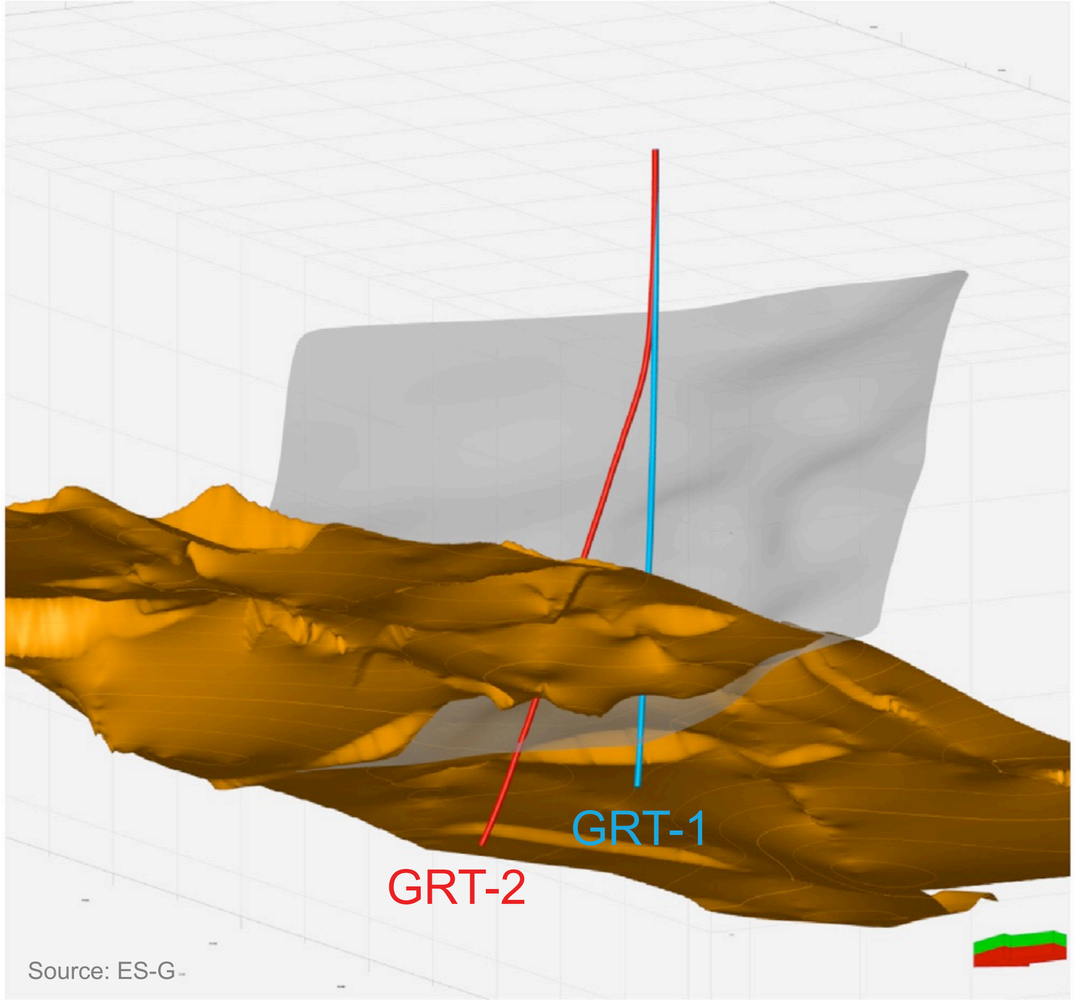
- View from North-West
- 3D structural model
  - GRT-1 (blue) / GRT-2 (red)
  - main fault structure
  - Top basement (orange) at 2200 m TVD

- GRT-1 Injectivity index:
  - 2.5 l/s/bar (at 70 l/s)
- GRT-2 Productivity index
  - Up to 3.5 l/s/bar
- No stimulation necessary for GRT-2

- Minor seismic events



Hydrothermal Alteration

- Fractured granite
  - Illite & calcite deposits within
  - vein alteration related to fractures

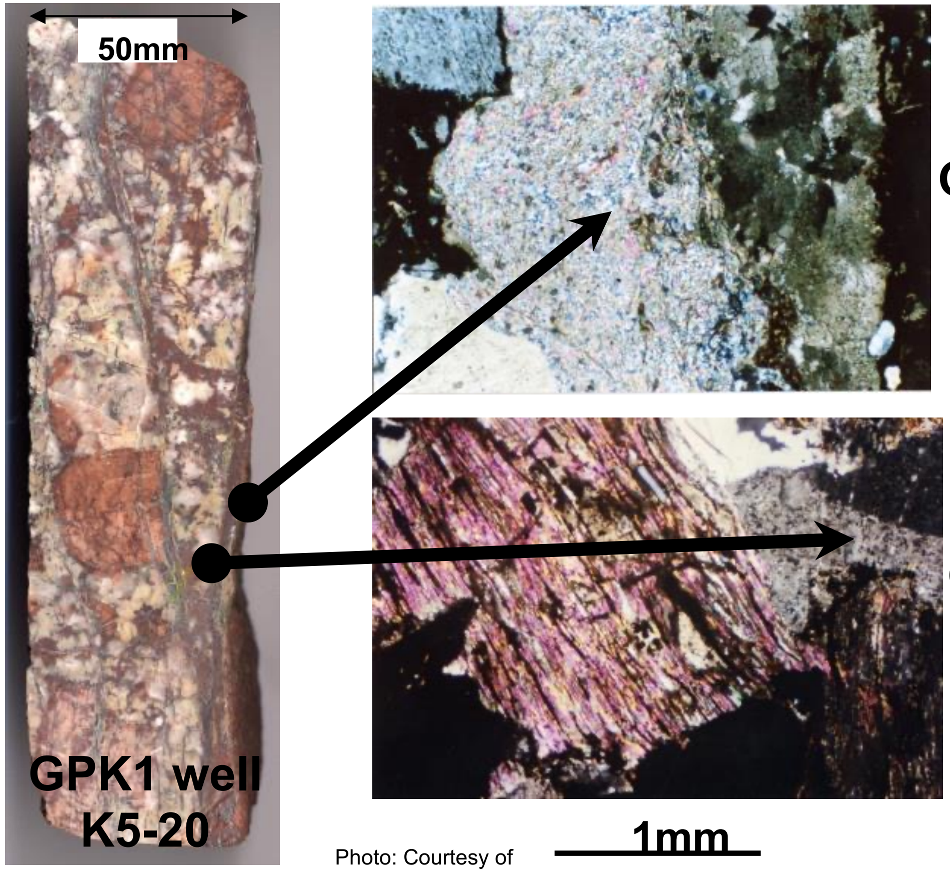


Photo: Courtesy of GEIE

Effect of alteration on hydraulic stimulation

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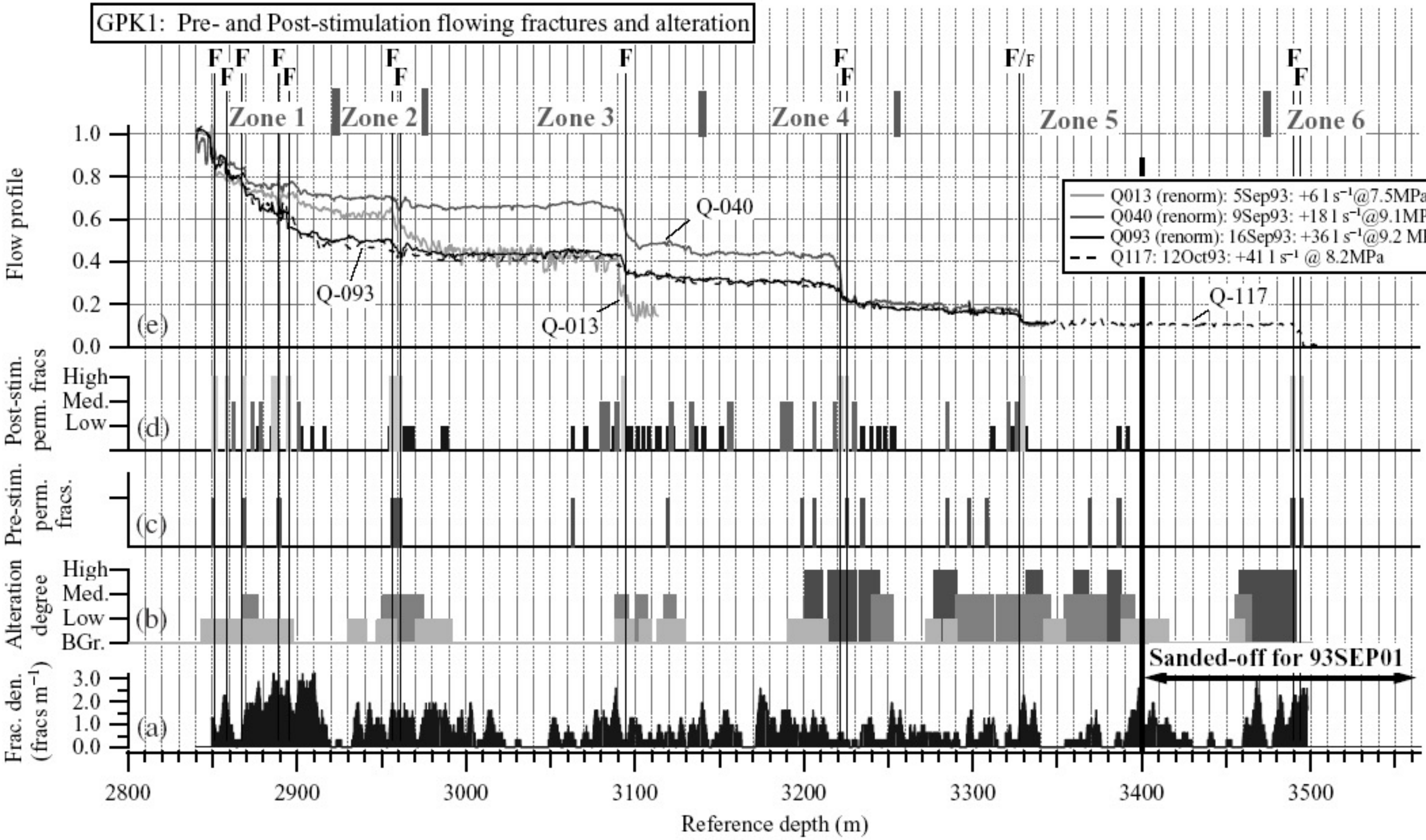
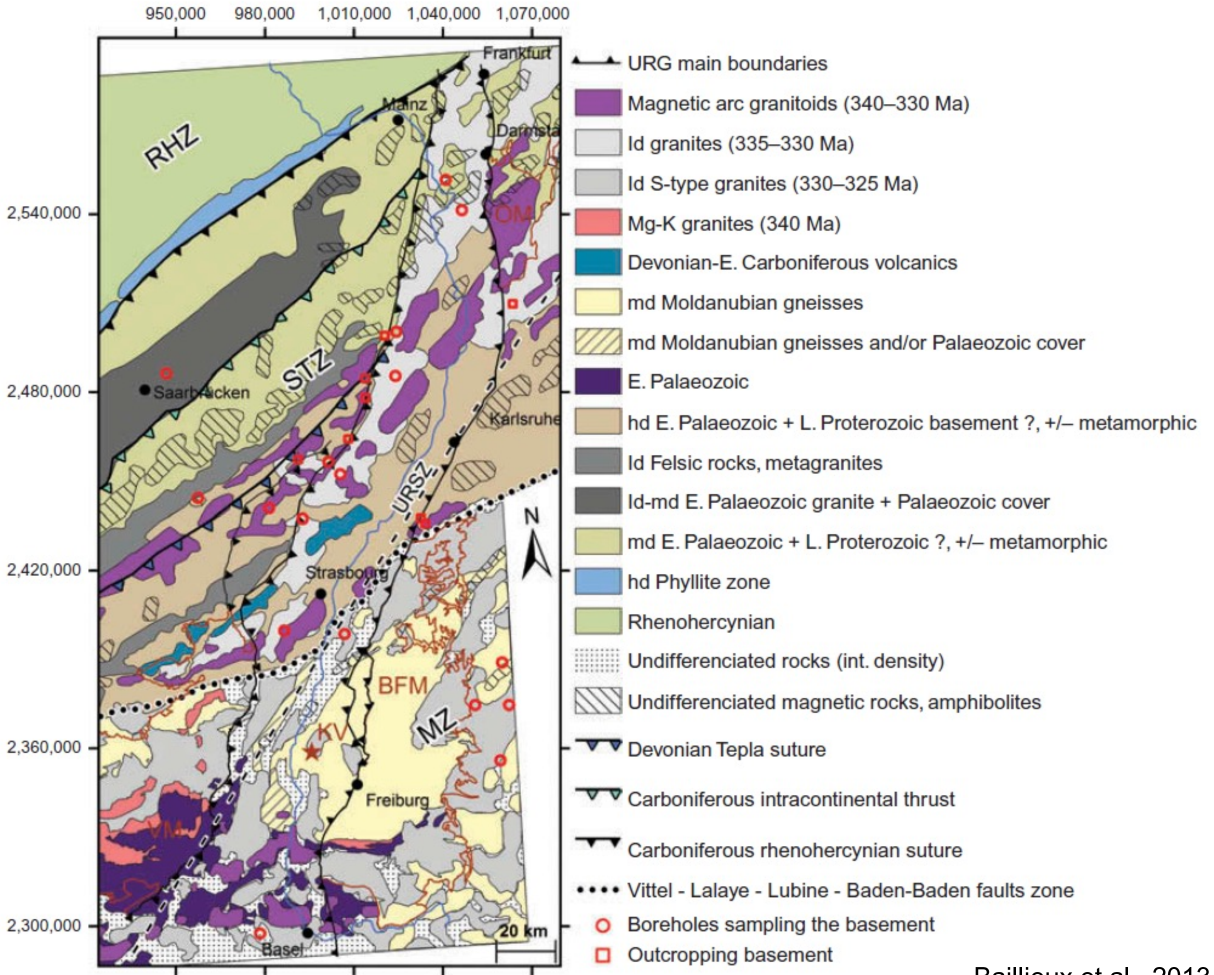


Evans et al. 2005

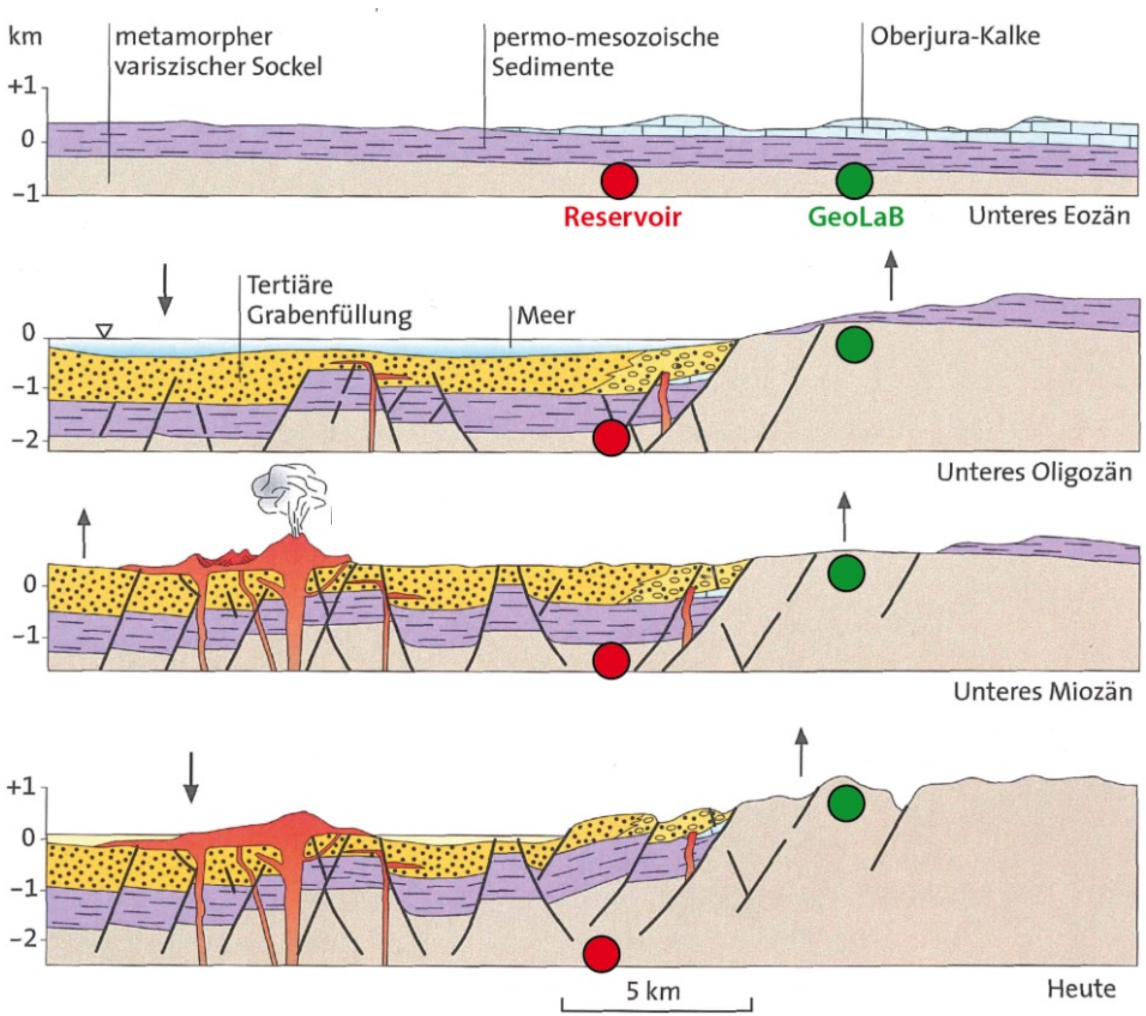
Crystalline basement in the URG

- Soultz-sous-Forêts



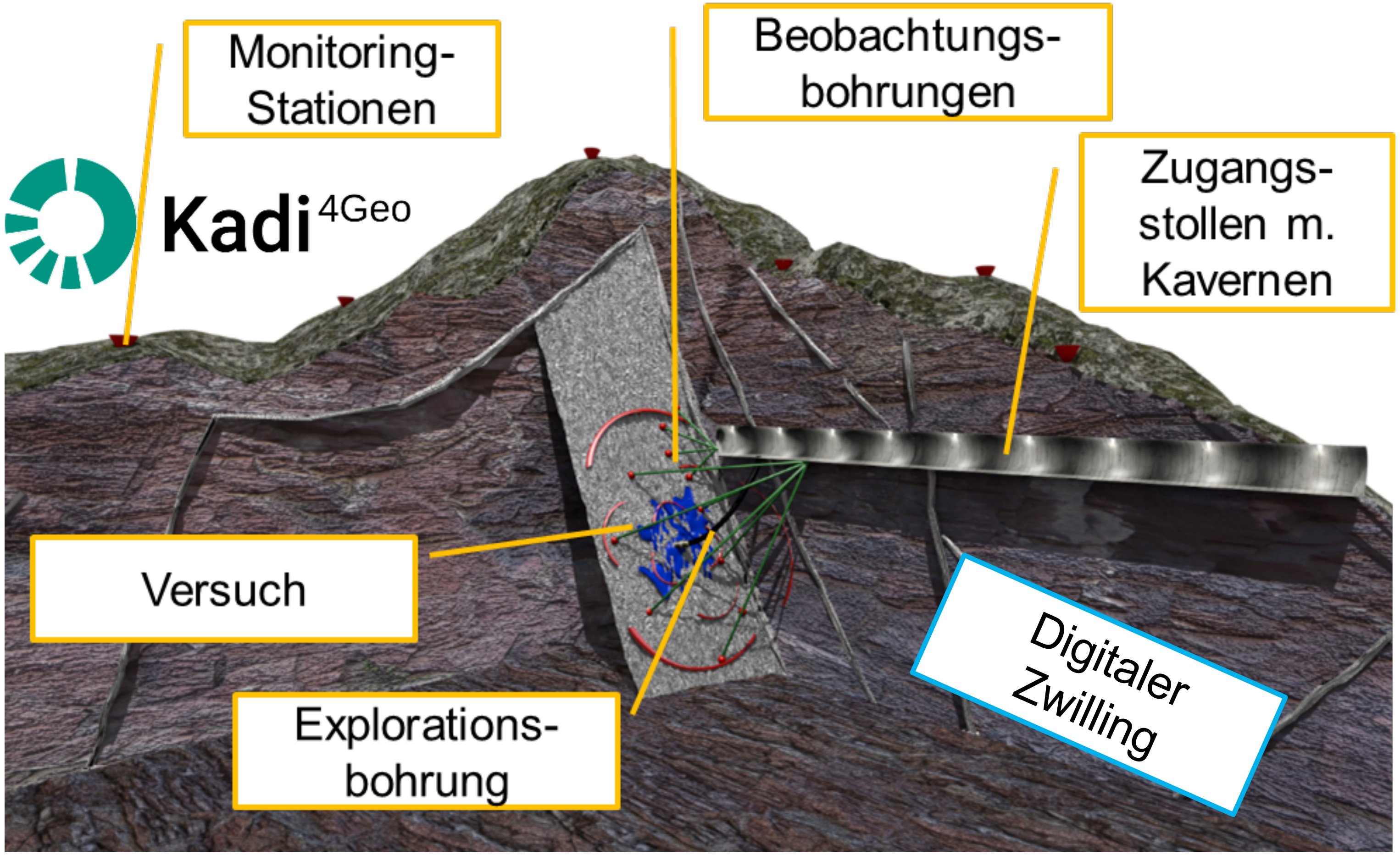
Baillieux et al., 2013

Reservoir and adjacent granitic mountains



Courtesy. Martin Meschede

GeoLaB: Reservoir simulator for controlled high flow experimentes

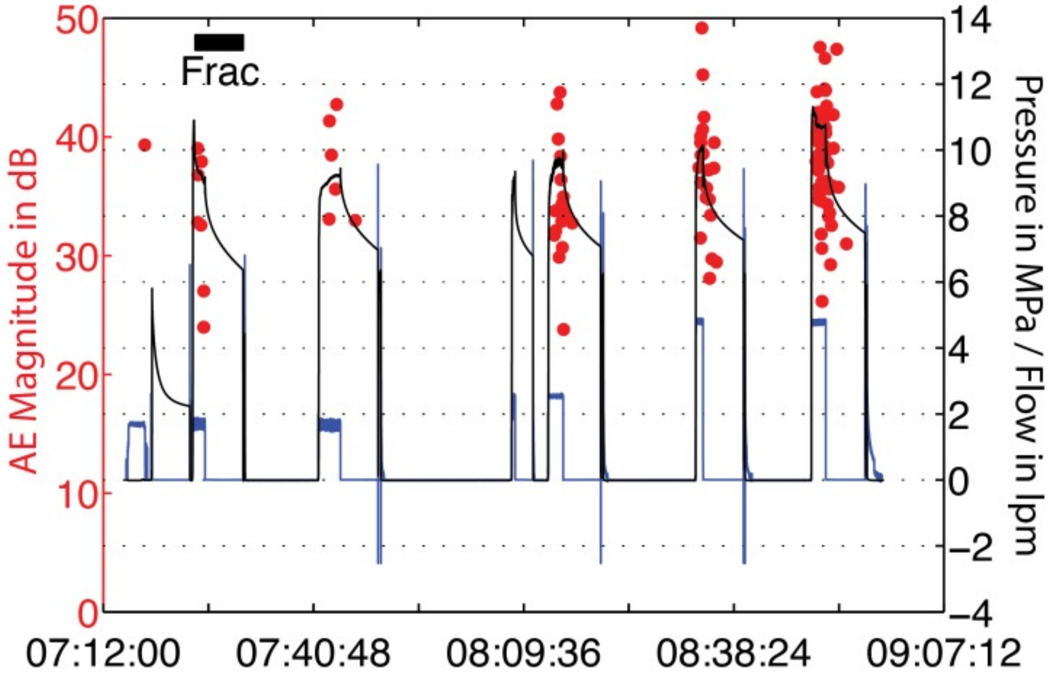


Schill et al. (2016)

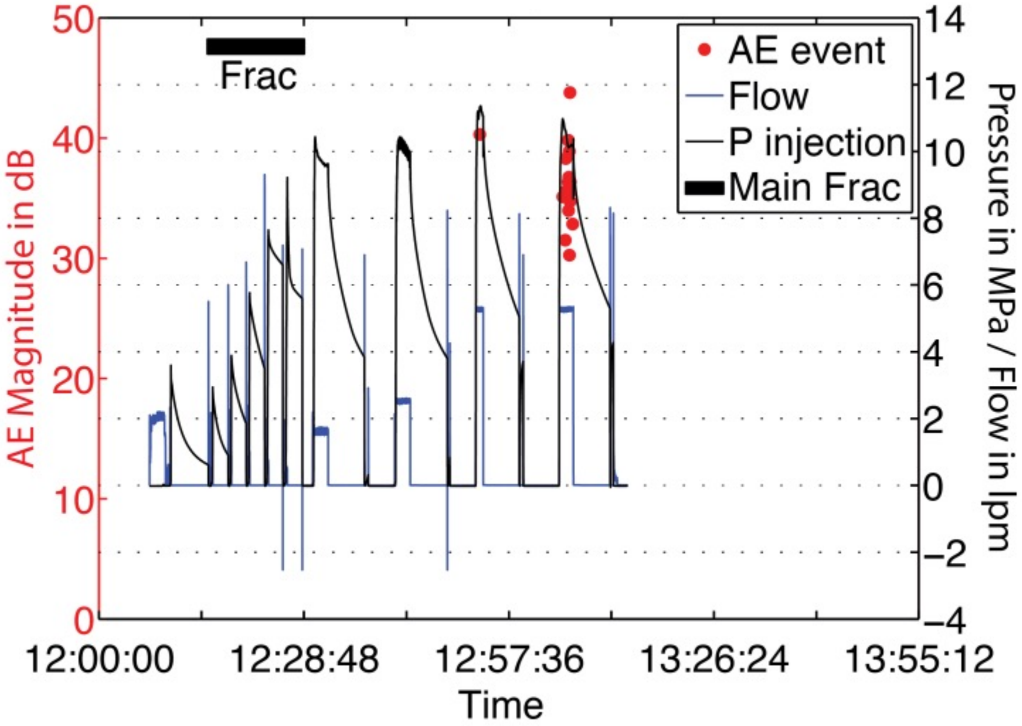
- GeoLaB-site criteria
  - **High flow rates** in crystalline fractured rock
  - Hydrothermal alteration
  - **Controllable hydraulic boundary condition**
  - **Reactivation of fractures**

Frac test in Äspö HRL in the granitic basement

- Conventional injection



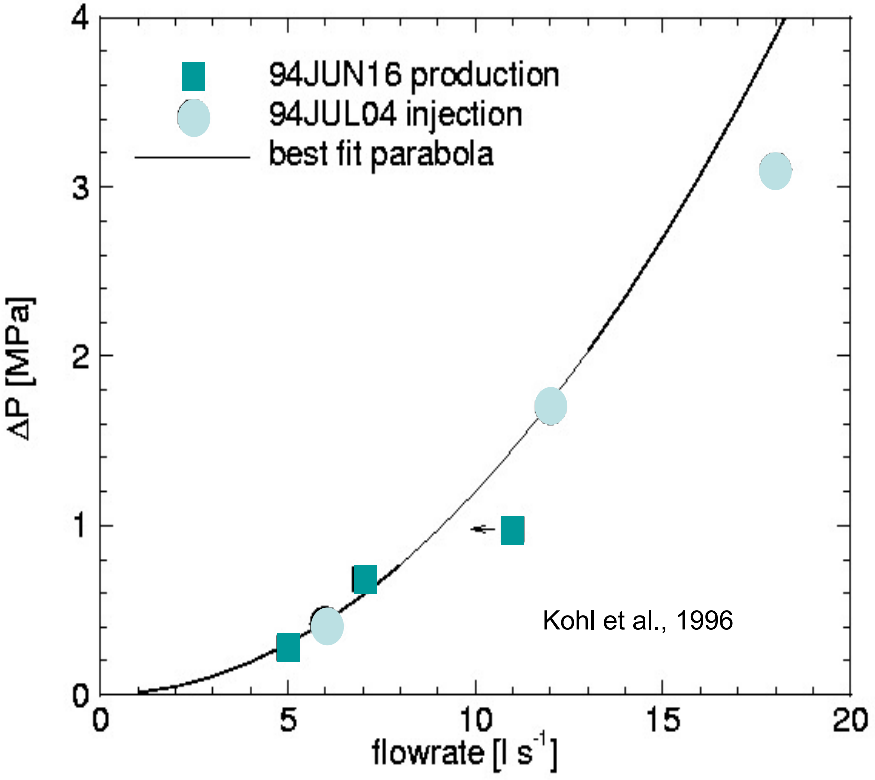
- Cyclic injection



Zang et al., 2017

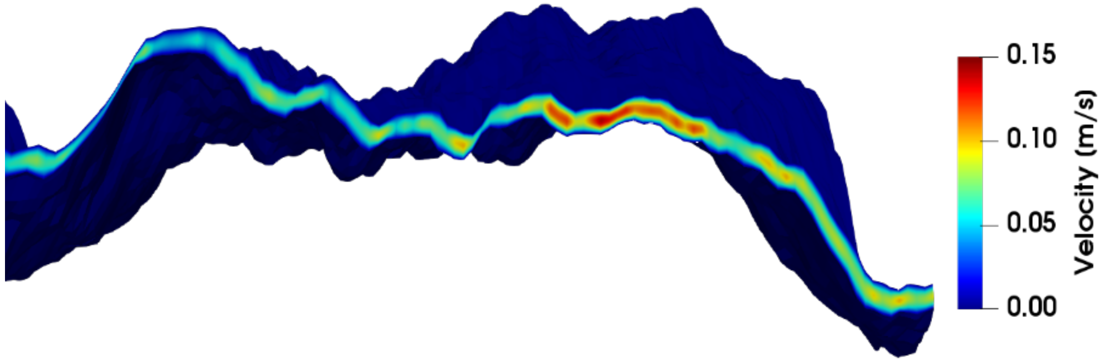
Wscientific goals: hydraulics

- Challenge: high flow rates in fractured media



Kohl et al., 1996

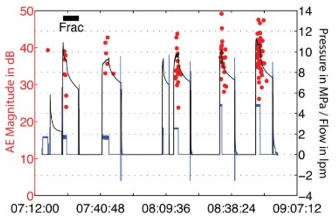
- Challenge: Mathematical description

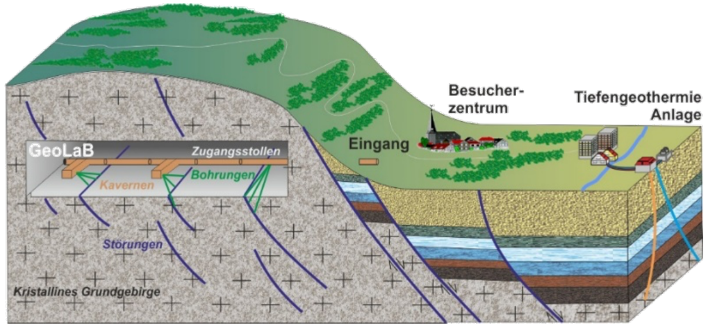


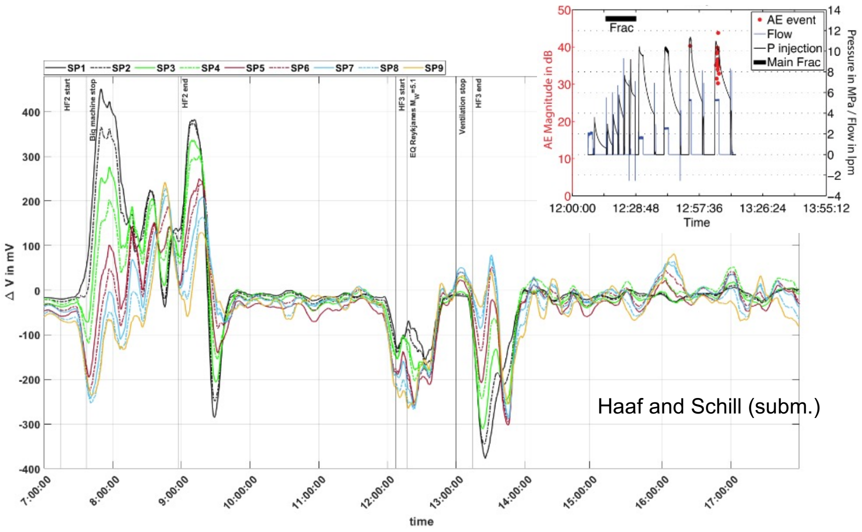
Marchand et al., 2020

Scientific goal:
Development of new monitoring techniques

- Observation on different scales

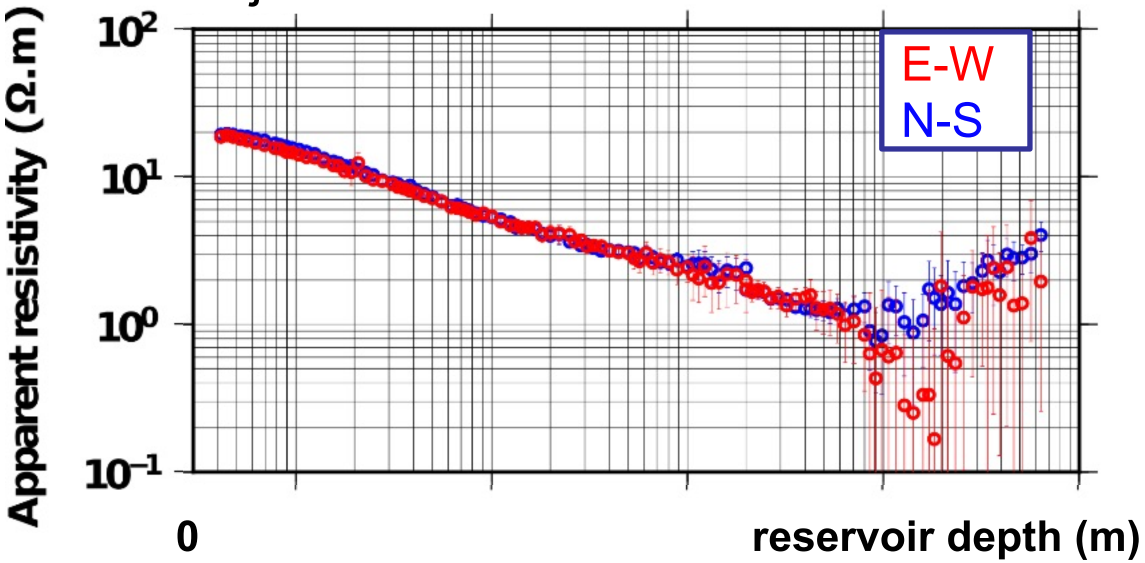






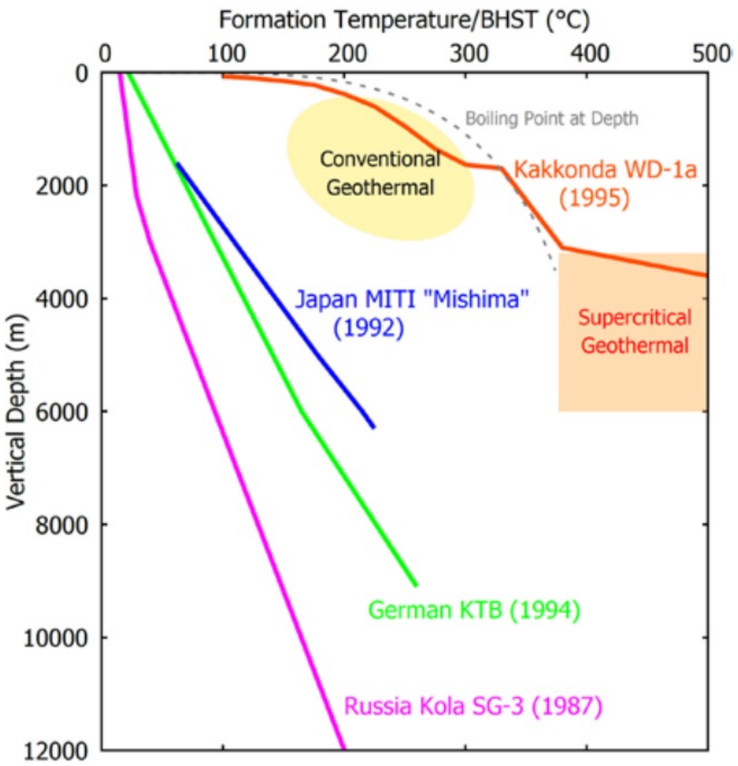
Haaf and Schill (subm.)

Injection in GRT2



Abdelfettah et al. (2018)

DEEPEGS



Ando and Nagawana (2020)