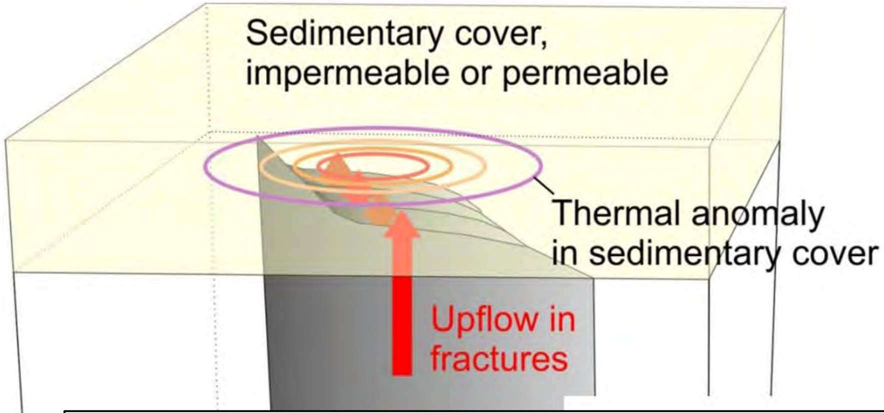
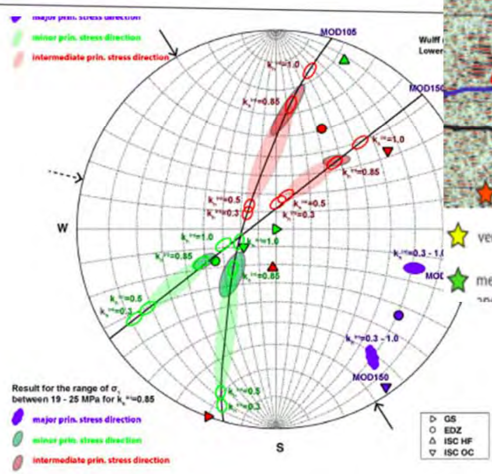
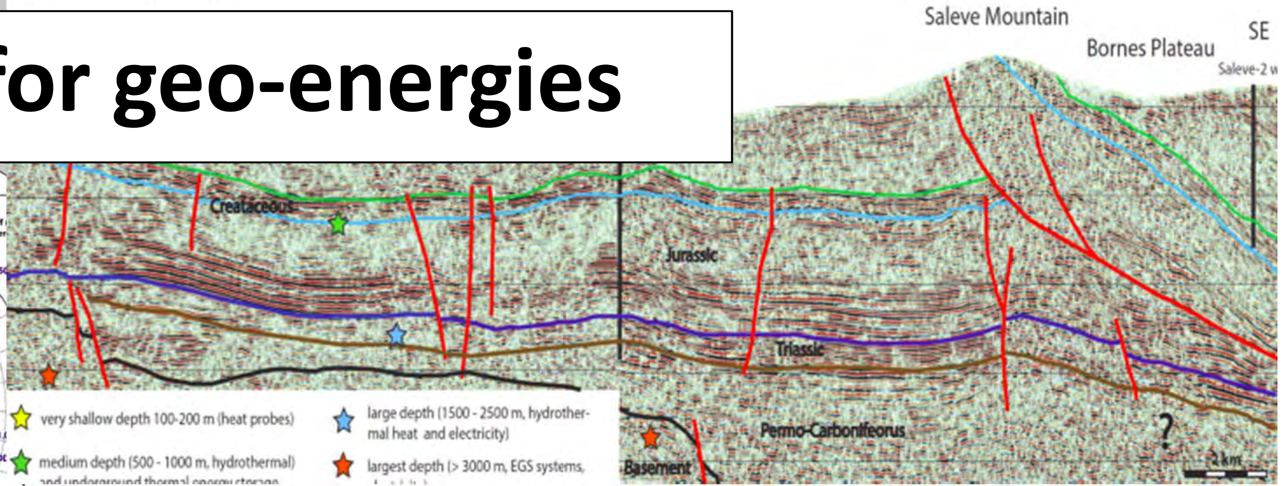


Challenges for geo-energies





Thomas Driesner

October 19 , 2016

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SWISS COMPETENCE CENTER for ENERGY RESEARCH
SUPPLY of ELECTRICITY

In cooperation with the CTI

Energy
Swiss Competence Centers for Energy Research

Schweizerische Eidgenossenschaft
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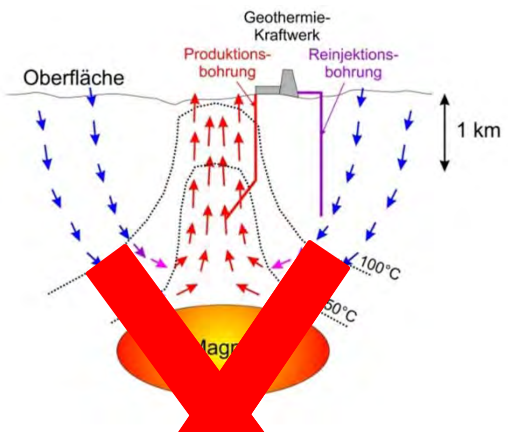
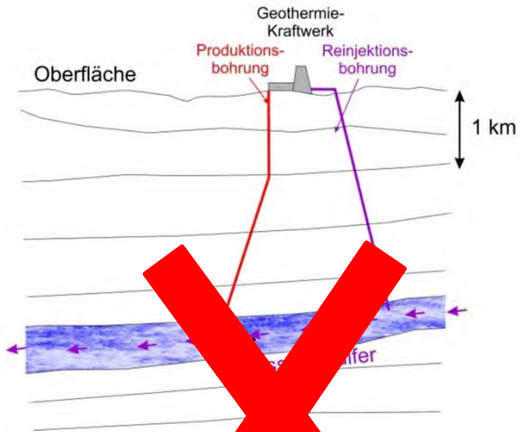
Commission for Technology and Innovation CTI

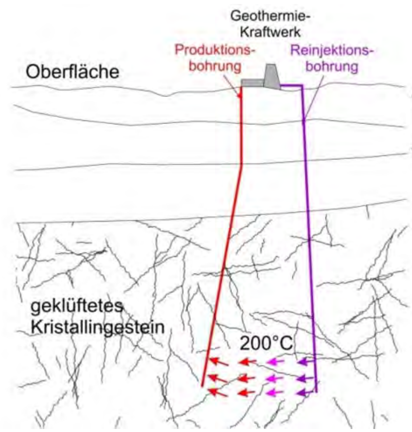
Three geo-energy plays: current challenges studied by our community

- **Deep geothermal energy for power production**
  - How can we find permeability at depth?
  - What is deep permeability anyhow?
  - Alternatively: can we engineer it? Physics and modeling of hydraulic stimulation
  - Grimsel experiment
  - Technological aspects: drilling techniques, well optimization, corrosion …
- **CO_2 sequestration**
  - Which geology is favorable and where to find it?
  - What are the problems associated with storage?
- **(Not so) deep geothermal direct heat usage & storage**
  - Exploration and operation

Deep Geothermal for Power







High Enthalpy

- Established
- Commercial
- Only in volcanic areas

Not in CH

Hot Aquifer

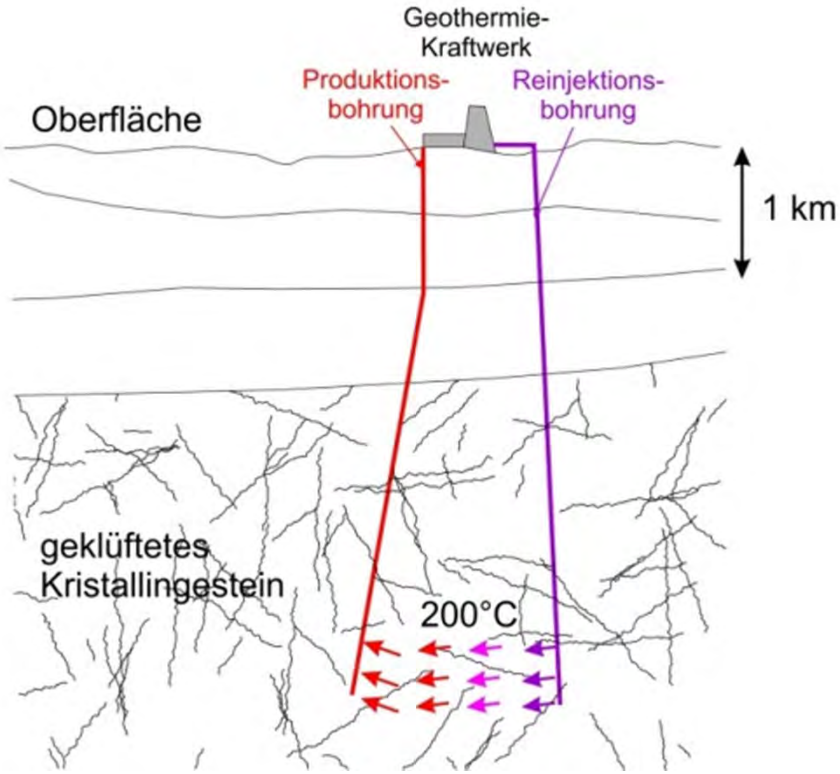
- Rather new
- Commercial
- Mainly heat

Not for power

Petrothermal Systems

- Future Technology of EGS (Enhanced geothermal systems)
- Pilot projects
- Focus of Swiss research

Two ingredients for geothermal power: temperature & permeability



Power

$$P = q\rho h$$

$$h = \int_{T_{ref}}^{T} c_P dT$$

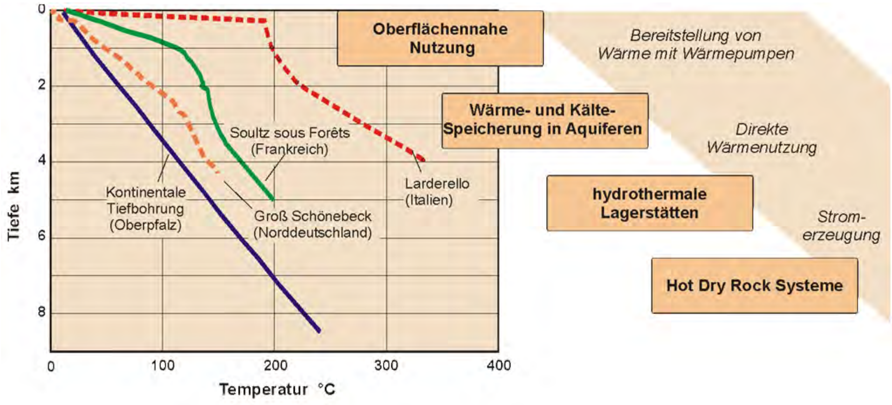
Darcy's law

$$q = -\frac{k}{\mu}(\nabla P - \rho g)$$

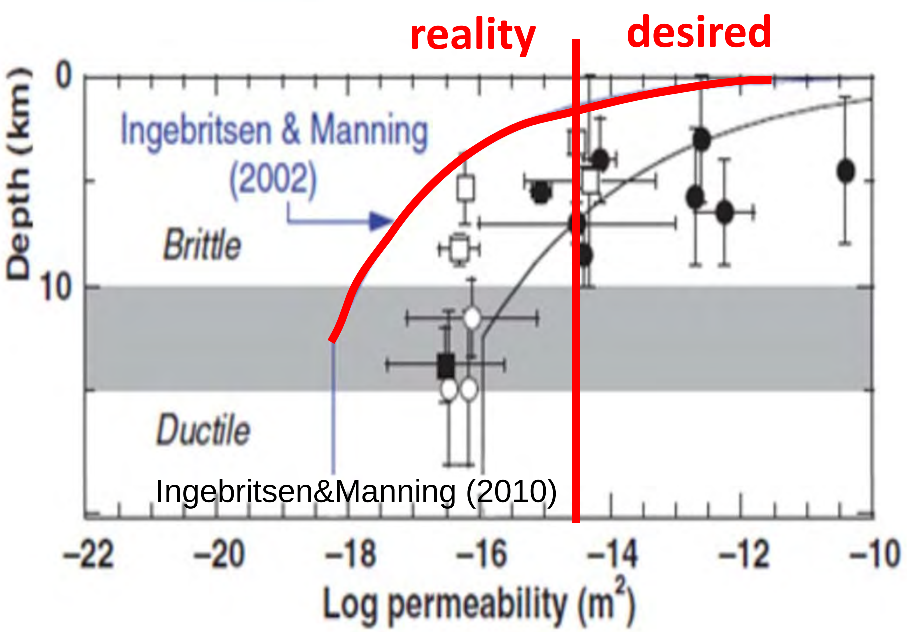
Higher T and higher k give higher P;

k most important

Two ingredients for geothermal power: temperature & permeability



© KIT



Higher Temperature:

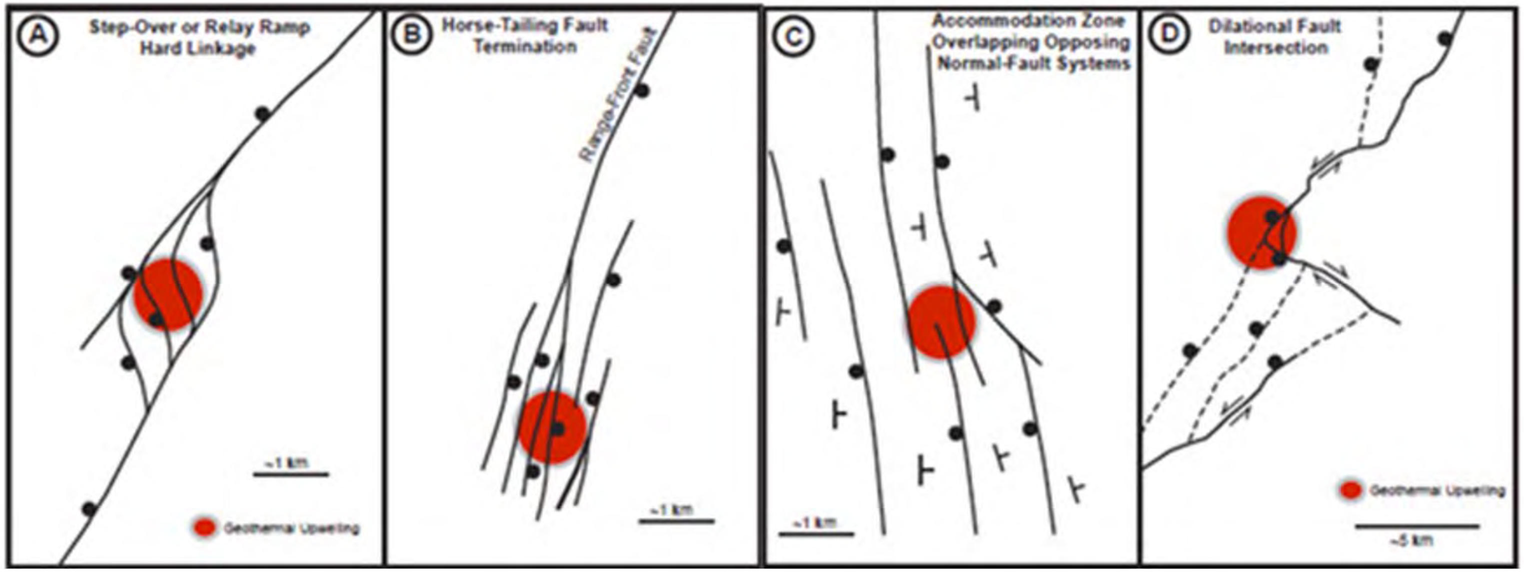
- just drill deeper: linear increase

Permeability:

- Drill deeper: logarithmic decrease ☹
- too low where temperature is high
- however: heterogeneous
- can it be engineered (?)

Challenges in deep geothermal energy for power production: Finding permeability at depth I.

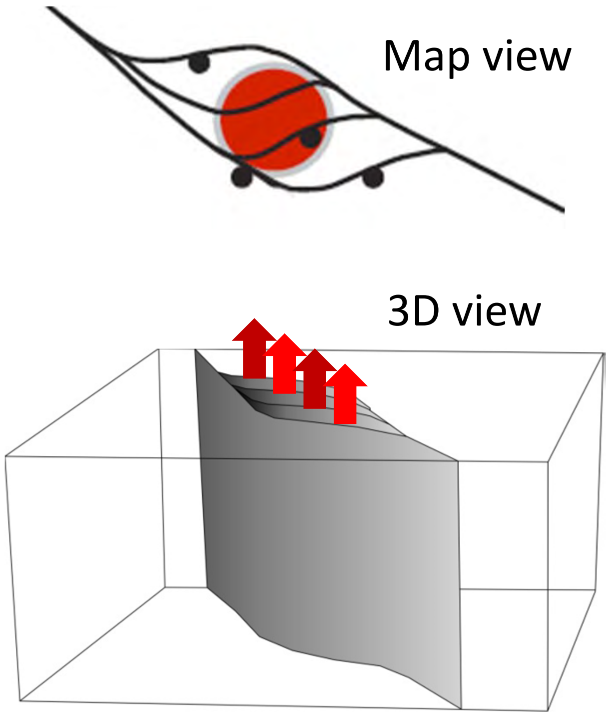
Natural geothermal systems at surface often located in specific structural settings:

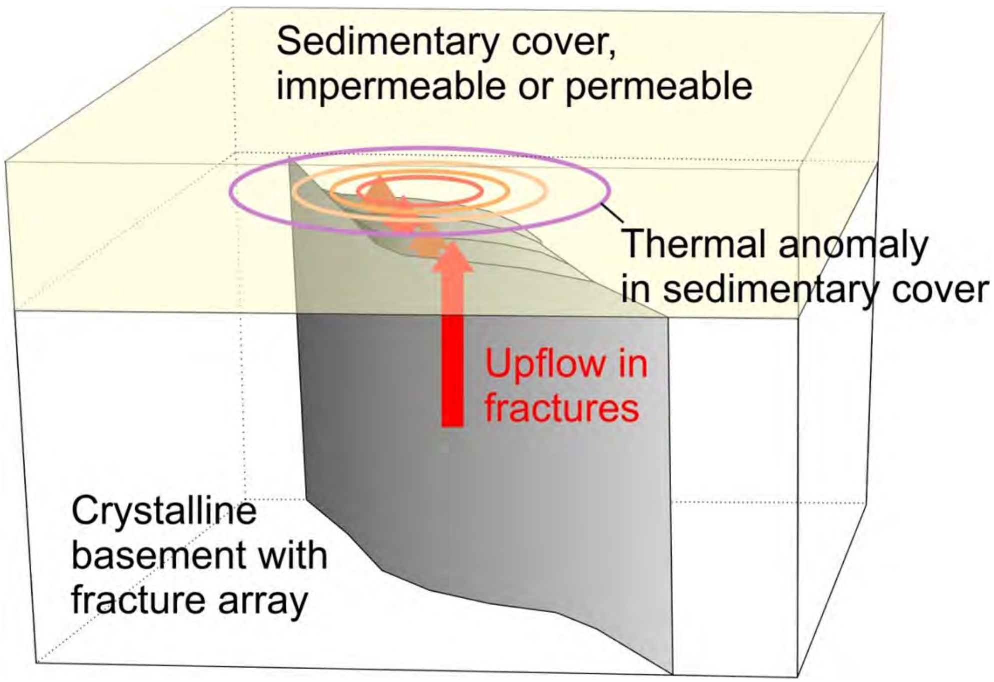


Faulds et al. GRC 2011

Challenges in deep geothermal energy for power production: Finding permeability at depth II.

What if one such structure was buried in geologic history but is still pathway for thermal fluids?

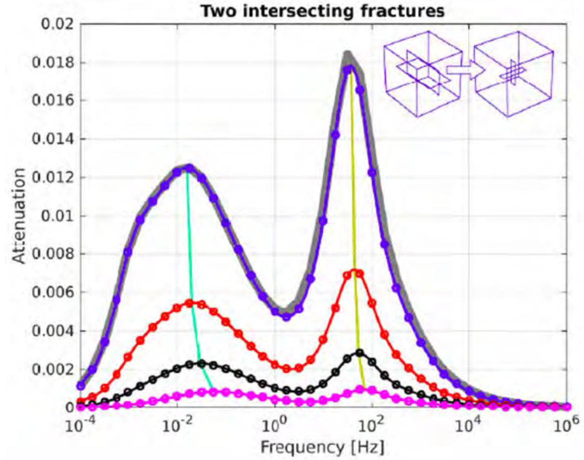


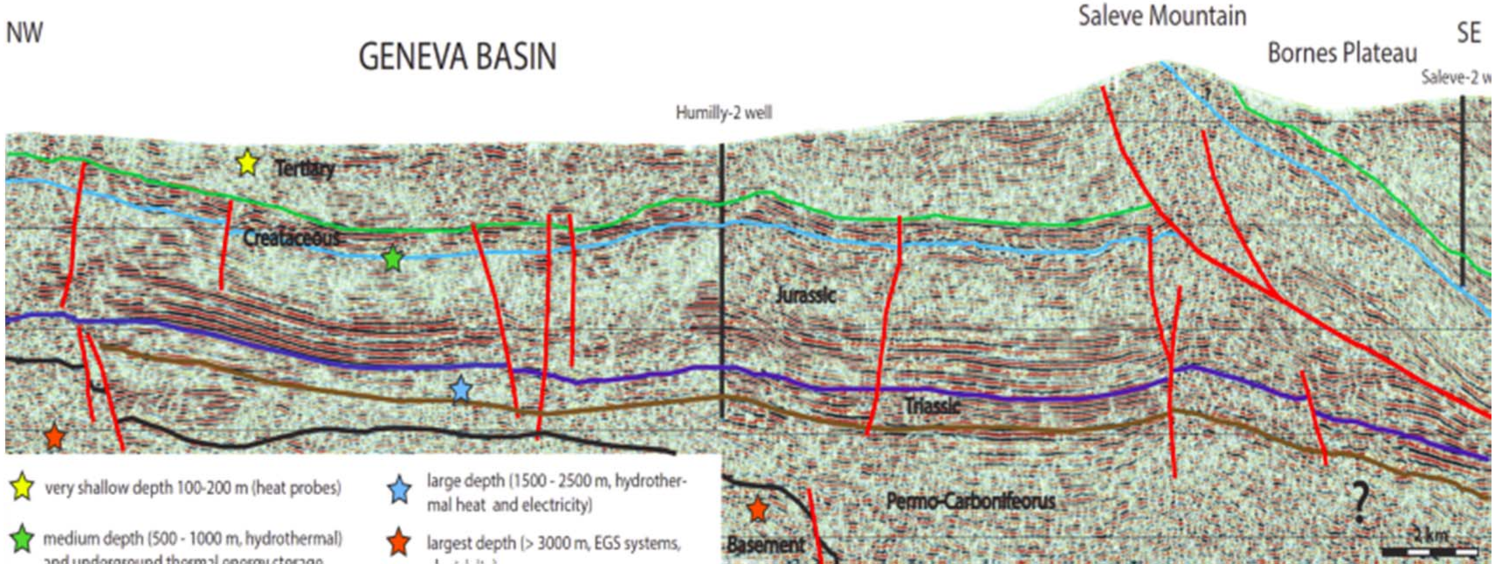


Challenges in deep geothermal energy for power production: Finding permeability at depth III.

Are there geophysical methods to detect fracture permeability at depth?

- Not directly
- What is the potential of bulk seismic properties of fractured rock masses?





Challenges in deep geothermal energy for power production: Finding permeability at depth IV.

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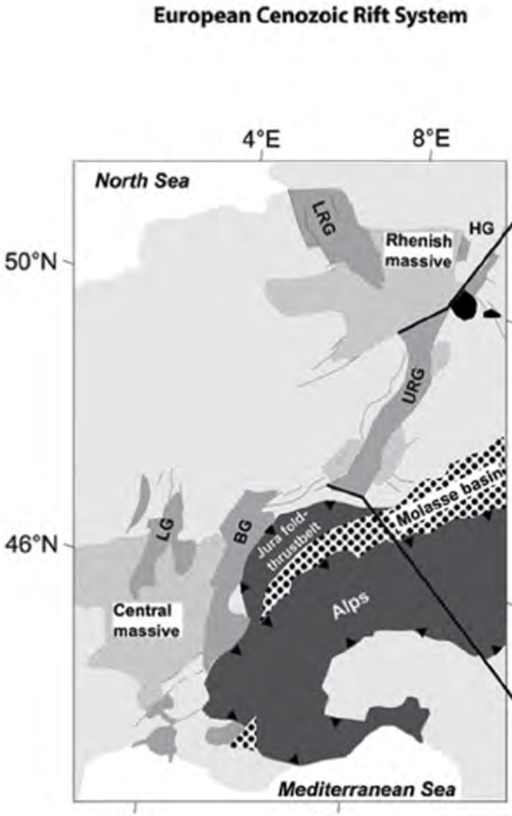
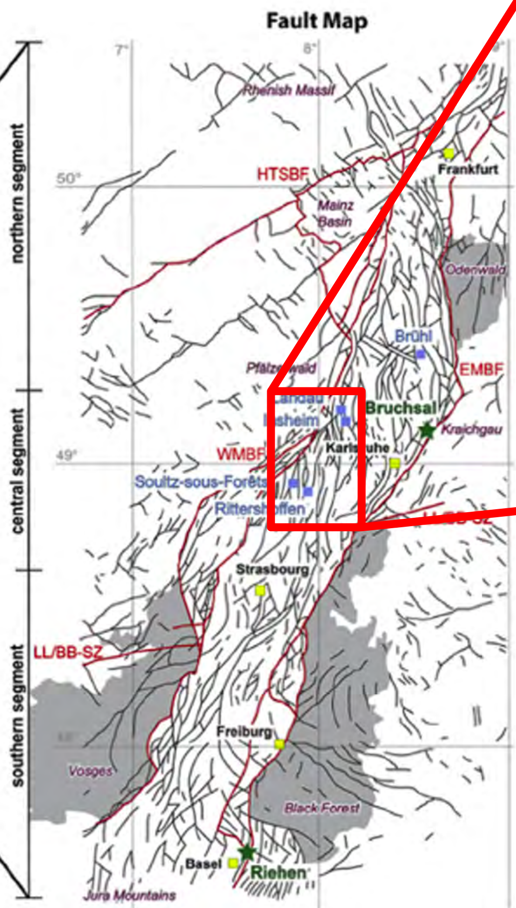
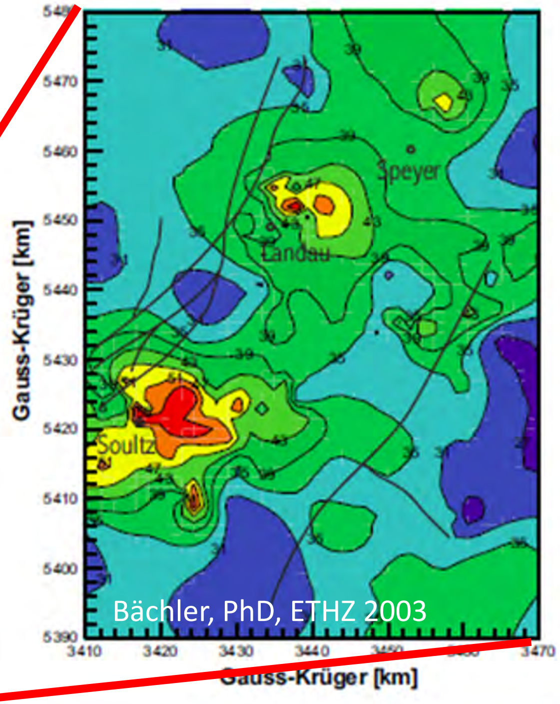
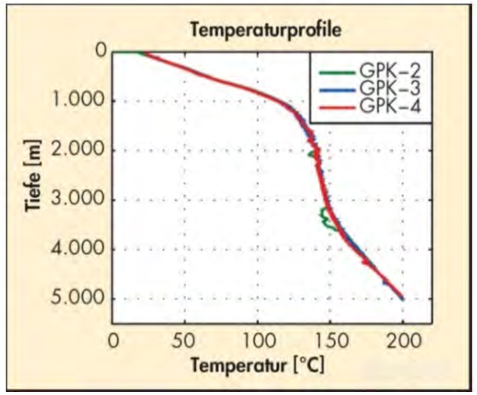




Meixner et al., 2016



Bächler, PhD, ETHZ 2003

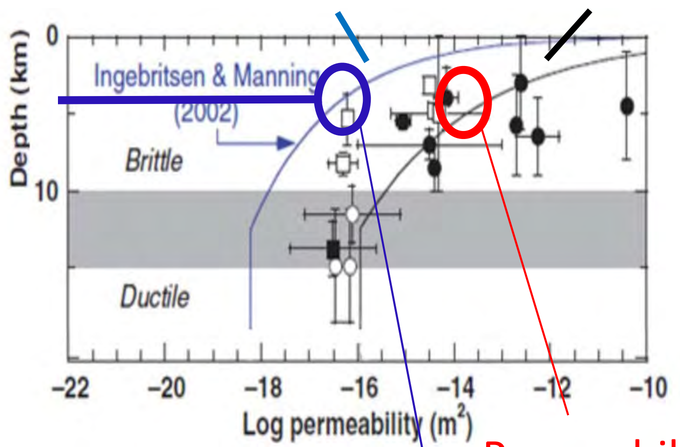


Deep geothermal energy for power: What is deep permeability? – I.

– Carnot efficiency ($\eta = \frac{T_{hot} - T_{cold}}{T_{hot}}$); deeper is better: higher T_{hot}

– Reservoir permeability controls how much hot water can be produced; deeper is worse: permeability decreases, too low for commercial production

– Permeability enhancement and "engineering" at depth is the #1 research priority, BUT: what is permeability in the first place?



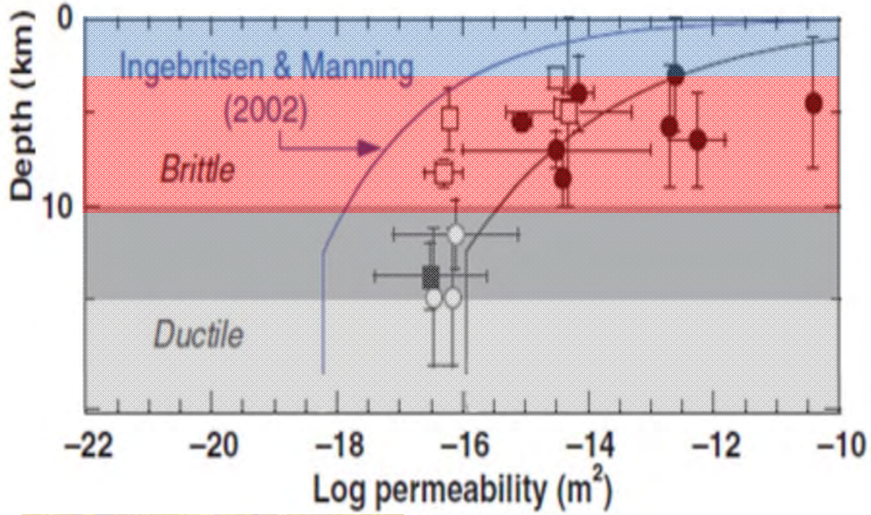
Deep geothermal energy for power: What is deep permeability? – II.

- Upper parts: porous medium, static "intrinsic" rock property, Darcy flow: $q = -\frac{k}{\mu}(\nabla P - \rho g)$

- Intermediate parts: fracture-hosted permeability, dynamic property (thought to be a self-organizing property, f(T, P, σ, chem, ...) -> so, what flow rates on what scale?

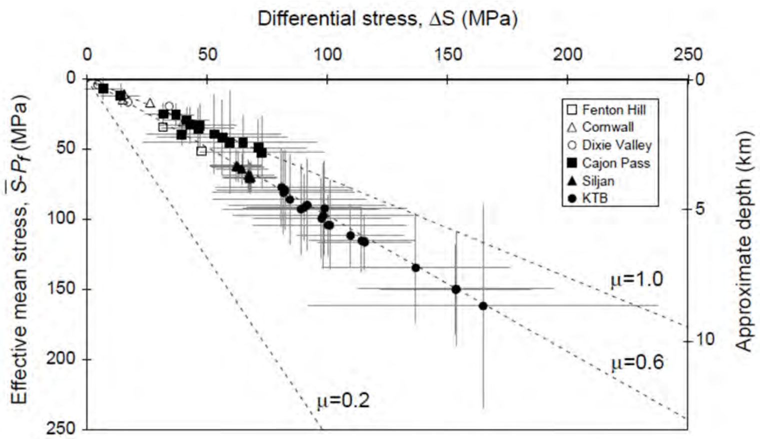
- Lower parts: transient phenomenon in ductile rocks

- Challenge: what governs this behavior?

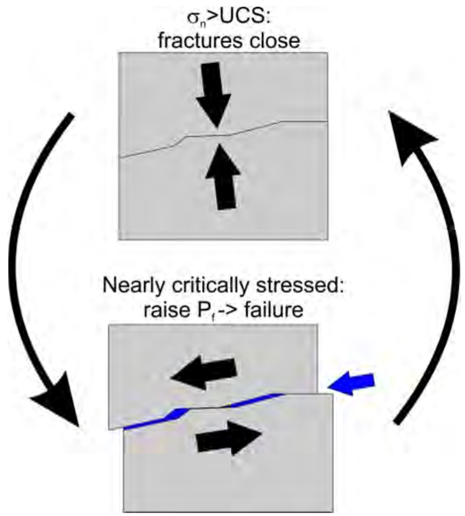


Deep geothermal energy for power: What is deep permeability? – III.

- Fractured crystalline crust nearly critically stressed
- -> Fluid pressure increase leads to failure
- Offset on rough fractures -> permeability increase
- If effective normal stress high enough, fractures close again
- In addition: chemical fluid-rock interaction
- Many aspects poorly understood

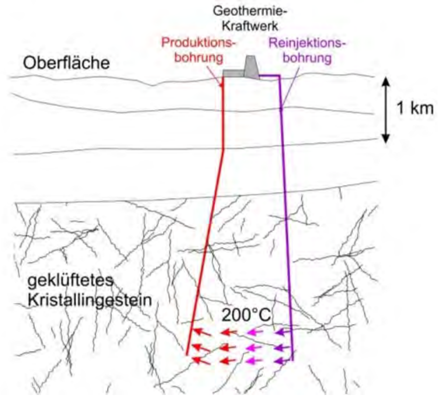


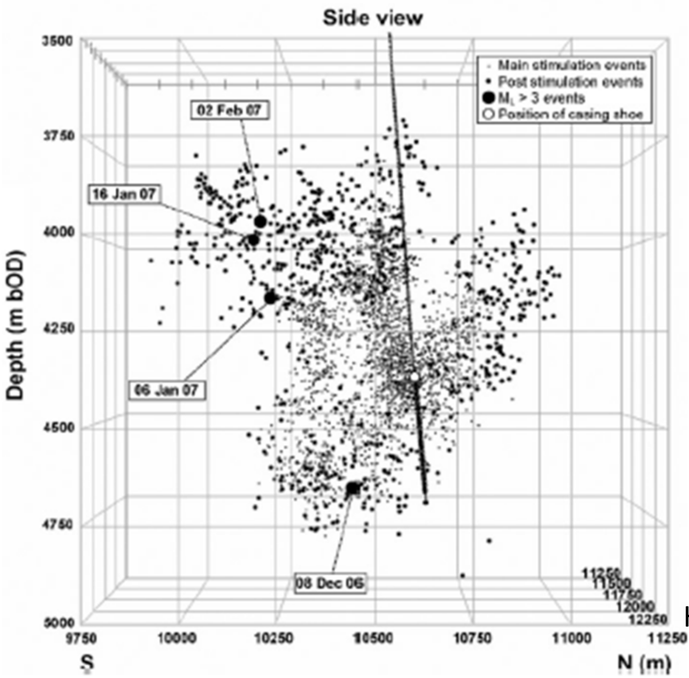
Townend & Zoback, 2000

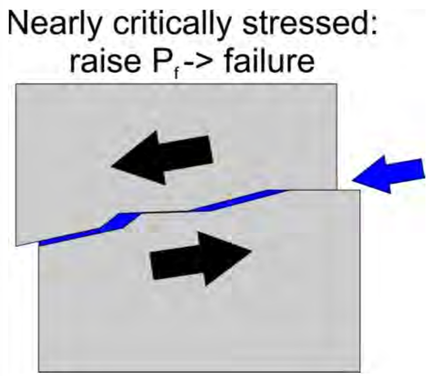


Deep geothermal energy for power: can we engineer permeability? Physics and modeling of hydraulic stimulation

- Remember: too low permeability at depth
- Make use of hydroshearing principle to increase permeability
- So far: trial and error
- Need: controlled results



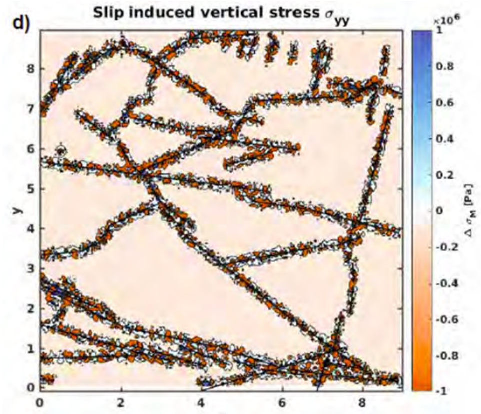


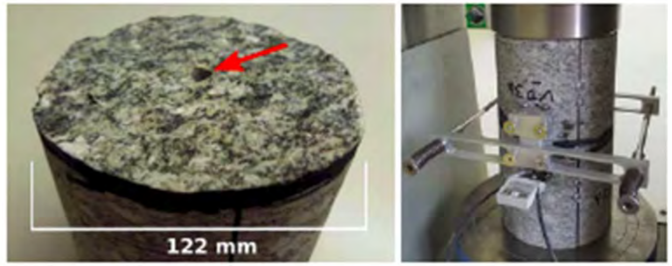


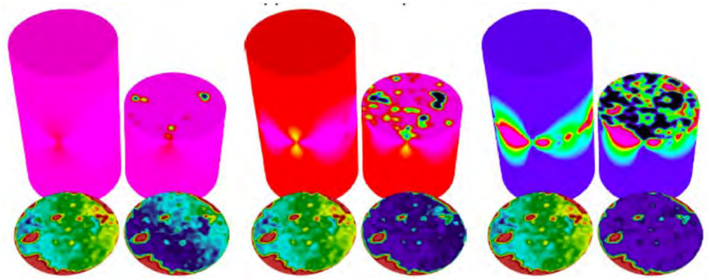
Häring et al., 2008

Deep geothermal energy for power: can we engineer permeability? Physics and modeling of hydraulic stimulation

- Develop the theoretical basis to go beyond trial and error and engineer fracture networks at depth
- Fundamentals of coupling between hydraulics and rock mechanics
- Numerical simulation and experimental studies
- Complex coupled processes acting on complex geometries
- Upscaling and Extrapolation?



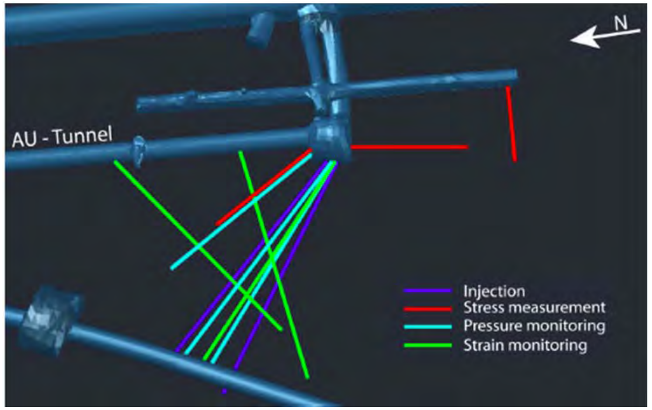


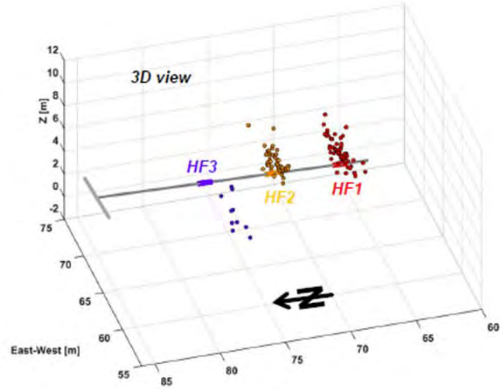


Deep geothermal energy for power: Grimsel experiment I.

- Hydraulic stimulation of shear zones in the Grimsel Underground Laboratory
- Baseline characterization: Stress, Hydraulics, Geology, …
- Detailed monitoring, experiment in Winter 2016/2017

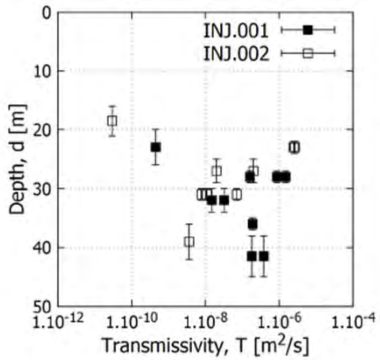
Deep geothermal energy for power: Grimsel experiment II.





Characterization phase

- Almost completed
- Stress tests and model
- Hydraulic testing
- Geophysical characterization
- Microseismicity monitoring
- …



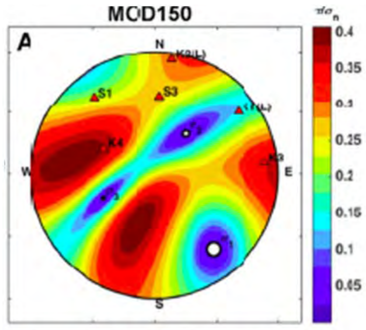
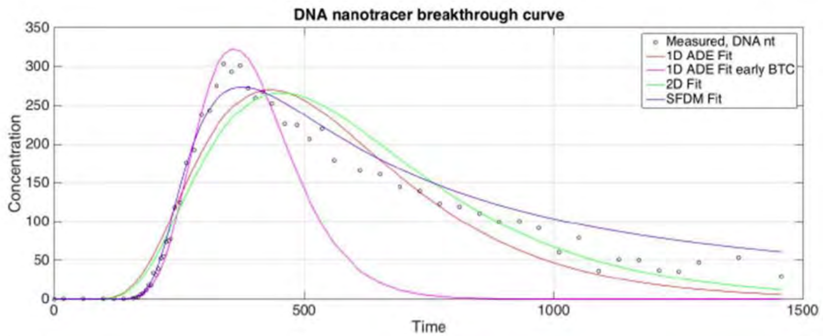


Figure 5: Slip tendency analysis



From contributions SCCER Annual Conference 2016

Deep geothermal energy for power: Grimsel experiment III.

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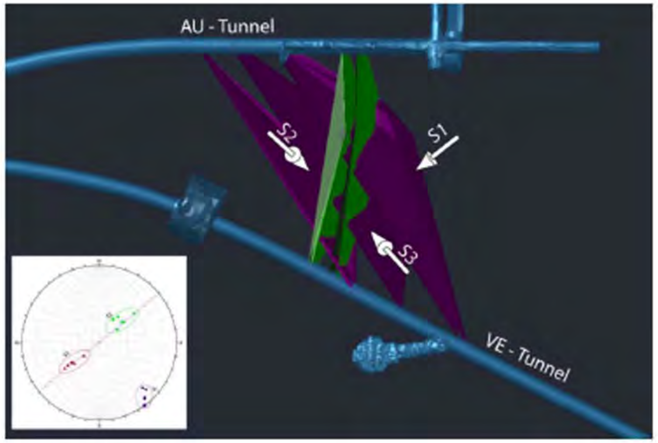
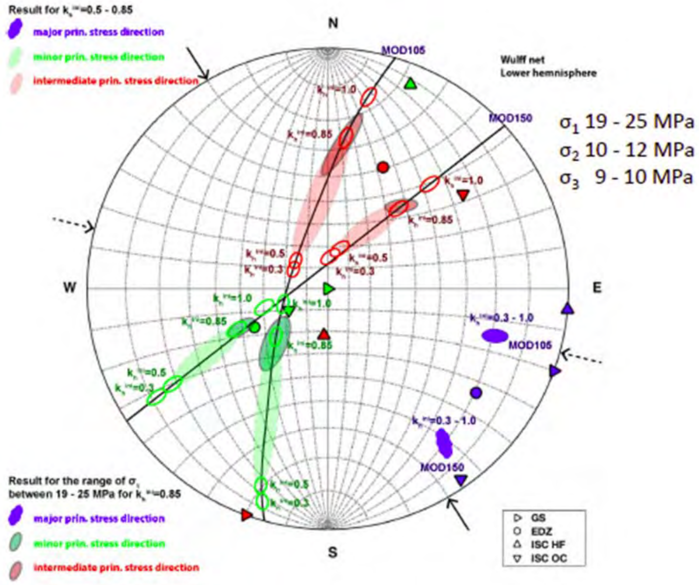
- Stimulation will be performed on shear zones through granitic rock
- Understanding of hydro-mechanical interactions
- Relation to micro-seismicity
- Development of stimulation protocols under controlled conditions
- Extrapolation to real reservoir conditions?

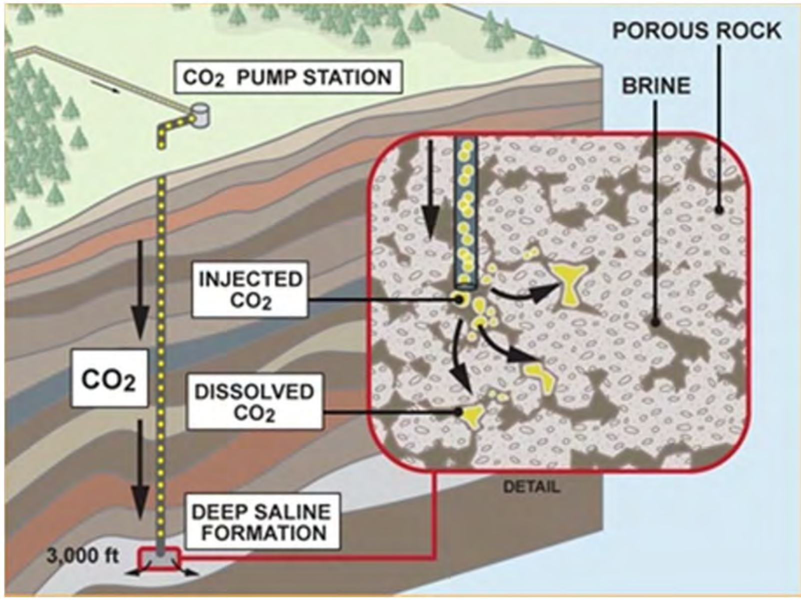




CO2 sequestration

Idea: pump CO_2 into porous rock at depth and store it there

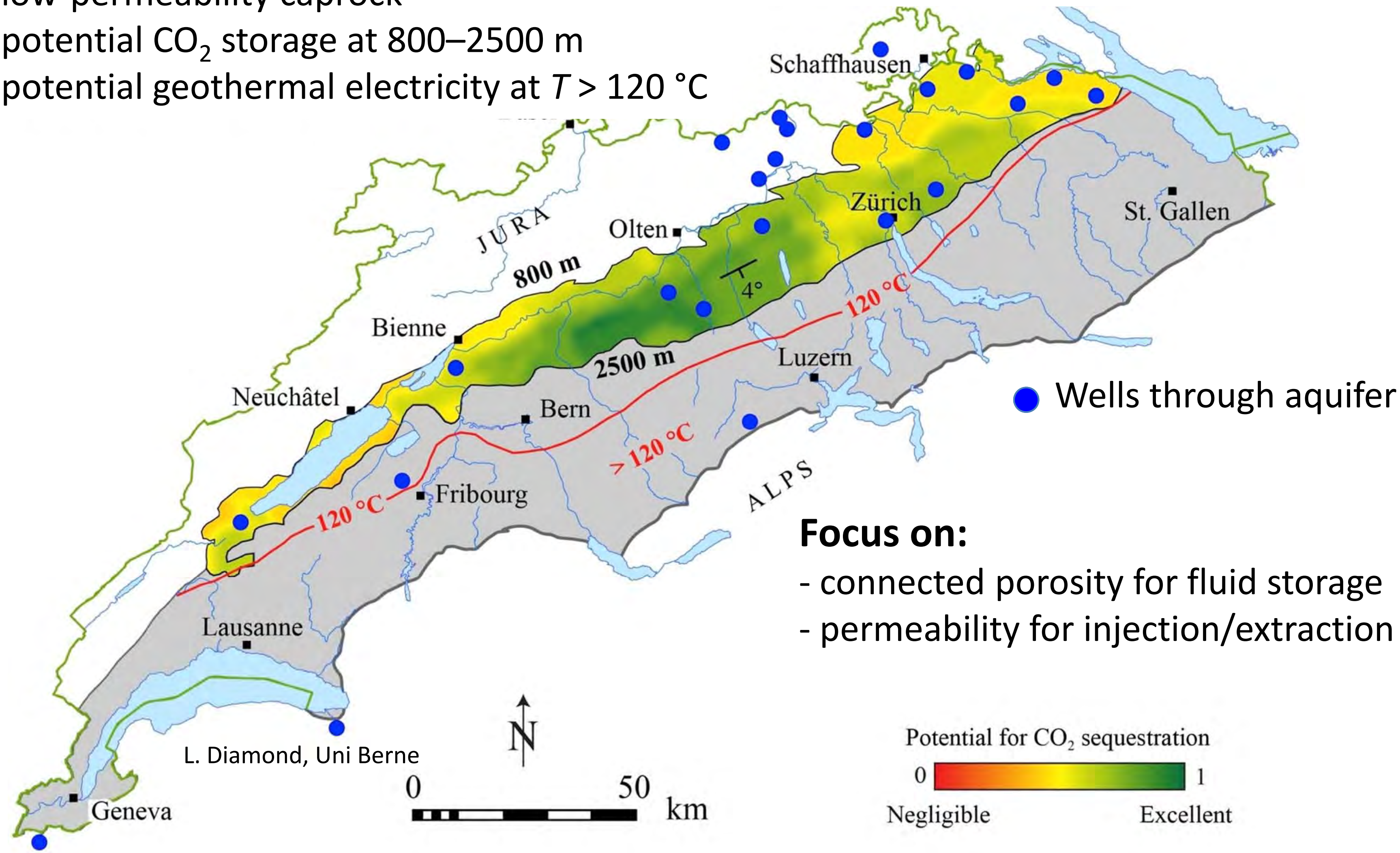
- Natural gas reservoirs show that storage is possible over geologic time scales
- However: need optimal situation, porous rock with tight cap – where to find in CH?
- Many aspects need research: cap integrity, CO_2 behavior in reservoir, …



CO2 sequestration: which geology is favorable and where to find it?

Regional Upper Muchelkalk aquifer:

- low-permeability caprock
- potential CO_2 storage at 800–2500 m
- potential geothermal electricity at $T > 120$ °C

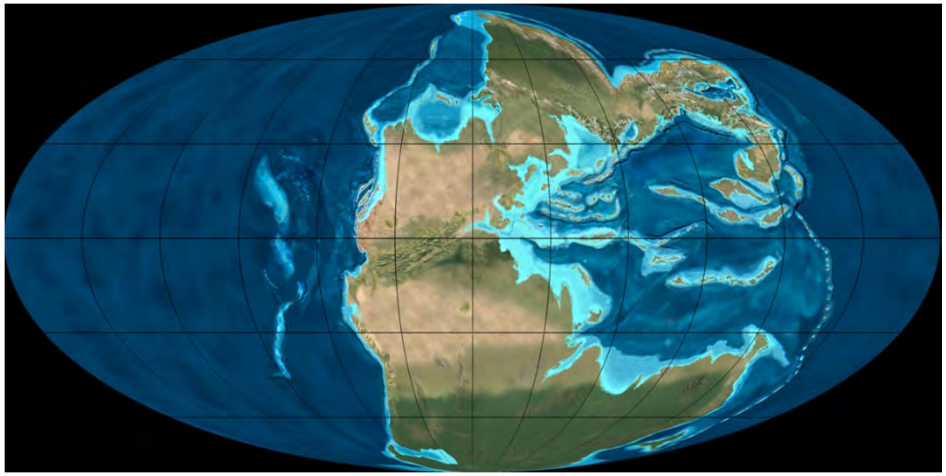


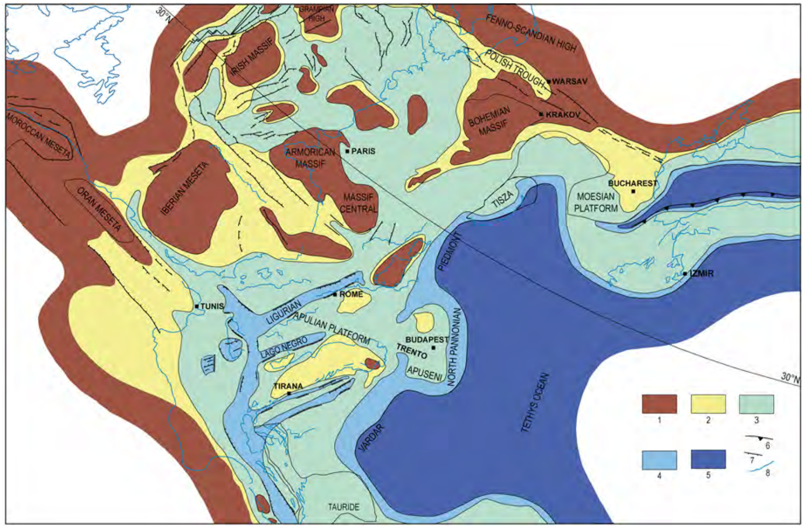
L. Diamond, Uni Berne

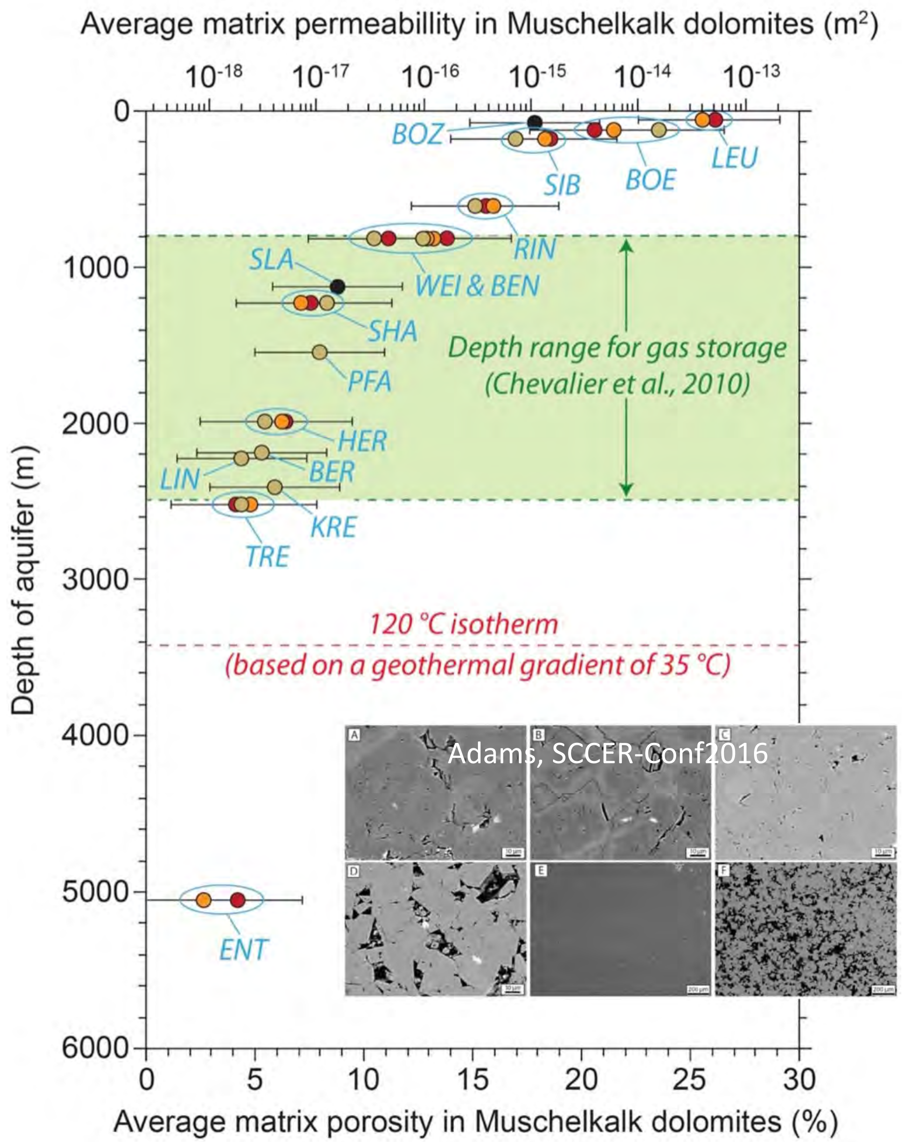
Focus on:

- connected porosity for fluid storage
- permeability for injection/extraction

CO2 sequestration: which geology is favorable and where to find it?



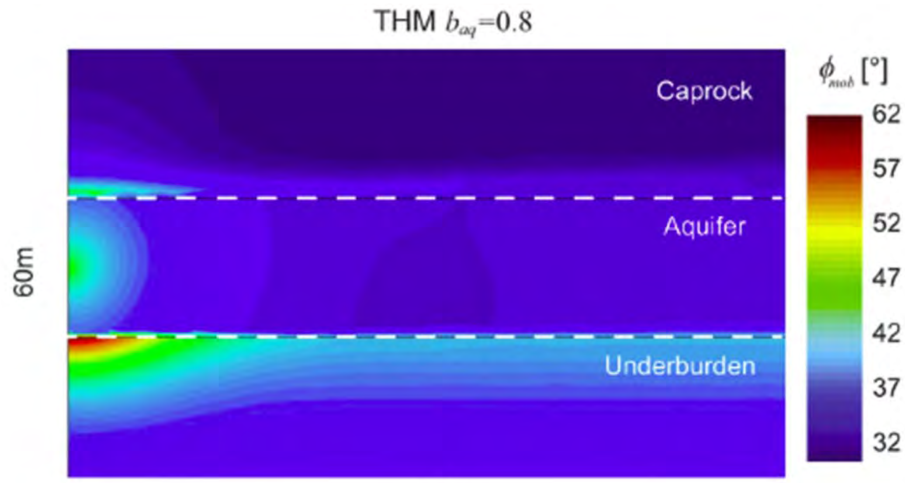




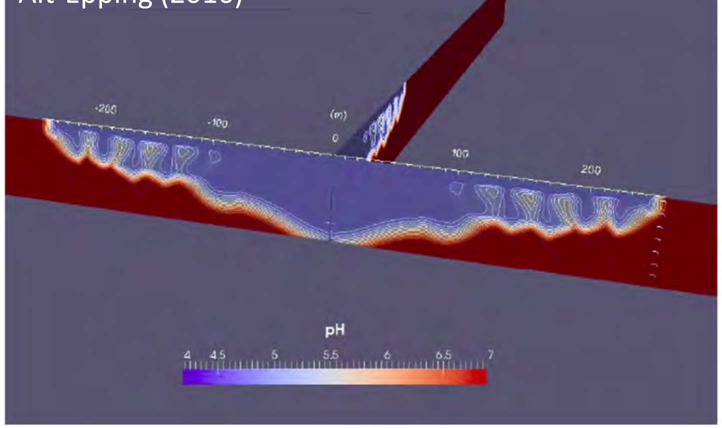
CO2 sequestration: What are potential problems associated with storage?

- Caprock integrity:
  - Reactivation of faults
  - Chemical resistivity
  - Thermal effects

- Storage mechanisms and long-term containment
  - From injection to capillary trapping to solution trapping
  - Permeability and porosity of cap
  - Migration of CO_2 plume



Li & Laloui (2016)



Alt-Epping (2016)

Workshop on Friday

Our initiative covers several of the most pressing challenges in deep geo-energy implementation in Switzerland.

In depth presentations will come in the workshop on Friday.

All groups, please contact me …

Thank you!