Karlsruhe Institute of Technology

Permeability and Fluid Flow in the Upper Continental Crust

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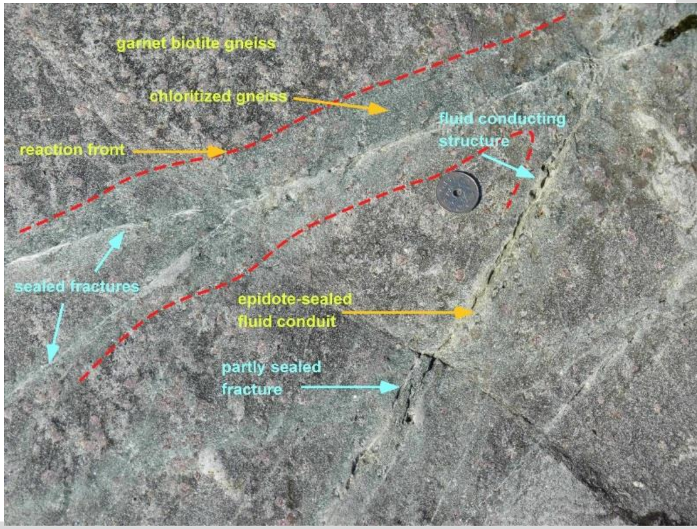
Outline

- Hydrogeologist‘s perspective
- Permeability of the Upper Continental Crust
- Fluid Flow in the Upper Continental Crust
- Stagnant fluids, an unrealistic concept
- Time dependent permeability variations
  (Kurt’s talk, focus on WRI-effects)

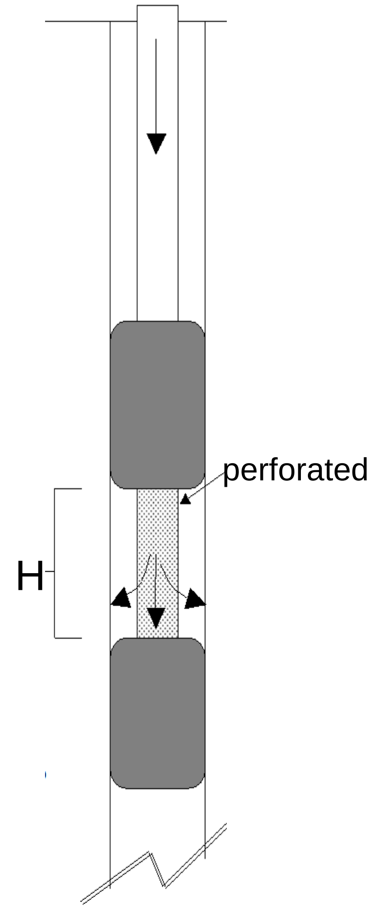


Hydrogeologist‘s perspective

- I would like to present some results of our ongoing research-work and the conclusions derived from these findings

- Permeability data are based on hydraulic tests (e.g. pumping tests)
  - in a test section H [m]
  - transmissivity T [m^2/s] of the tested rock
  - convert T into hydraulic conductivity K [m/s]
  - convert K into permeability κ [m^2], fluid parameters (ρ, μ) are needed.

- Investigation areas: Central Europe



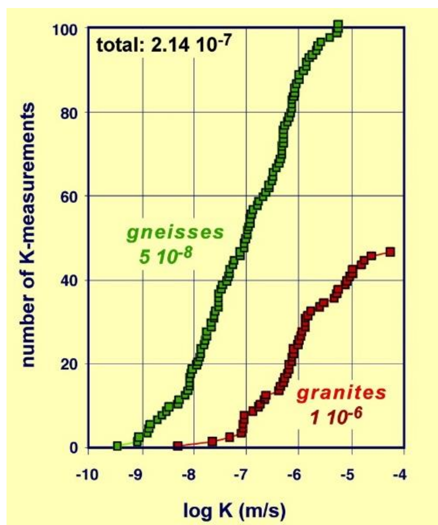
Permeability of the crystalline basement

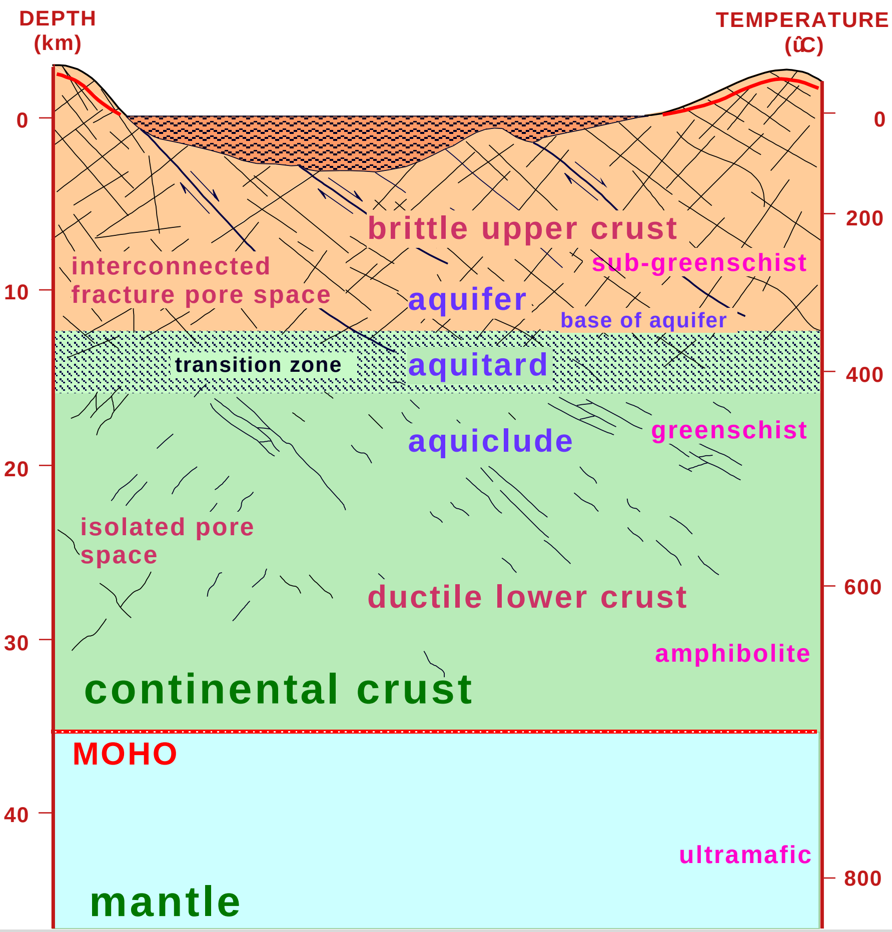
Interconnected water-conducting pore-space (e.g. fractures) in the Upper Continental Crust

In the upper 100 m <u>large variability</u> in permeability (several log-units), with highest values similar to those of gravel-aquifers.

In highly deformed areas <u>granites</u> seem to be <u>more permeable</u> than gneisses.

In poorly deformed areas the conductivity of granites can be very low.

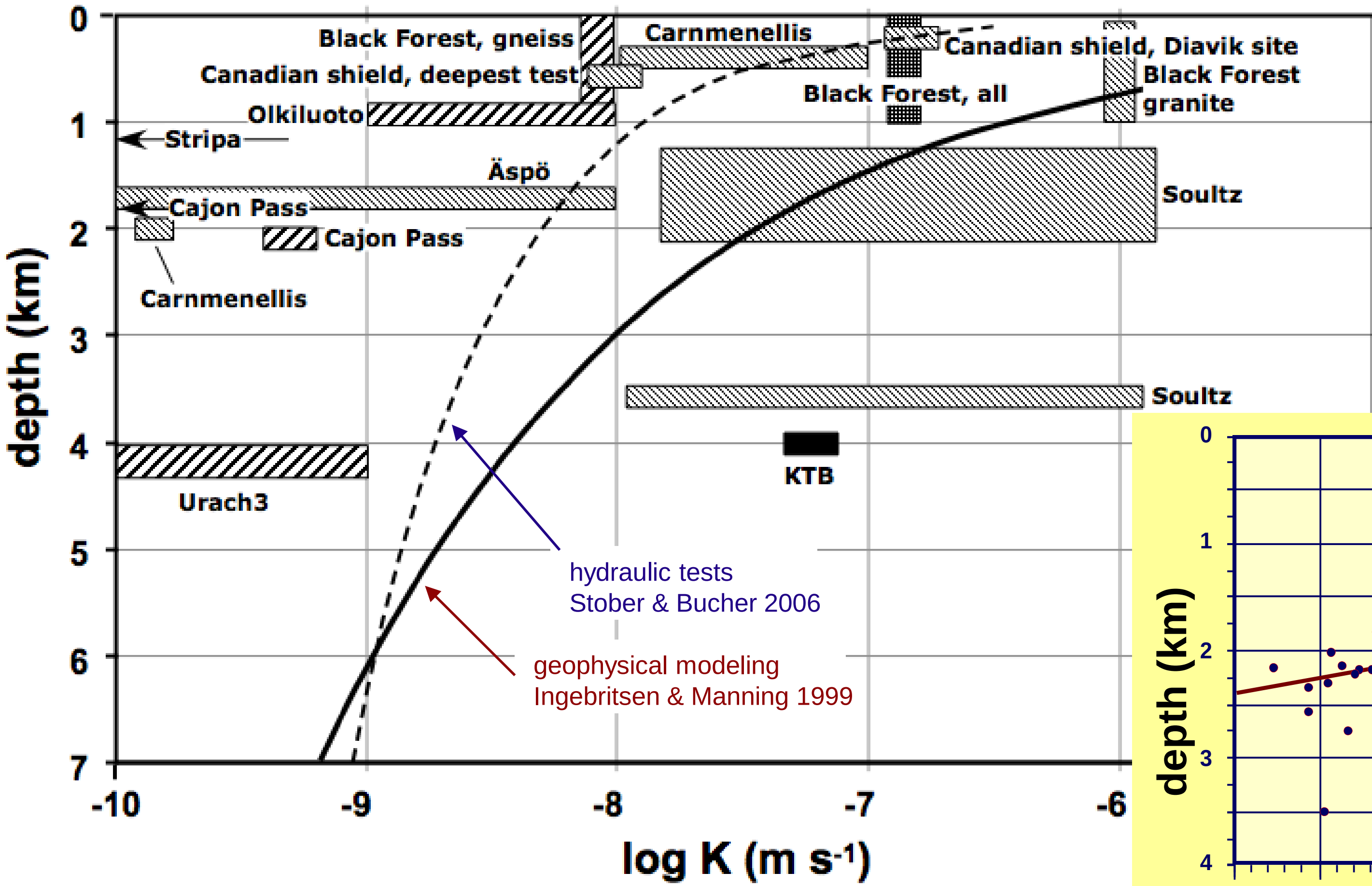


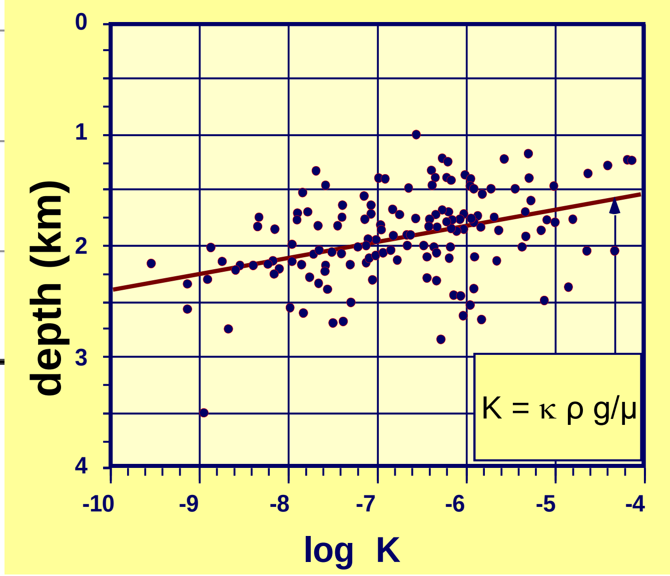


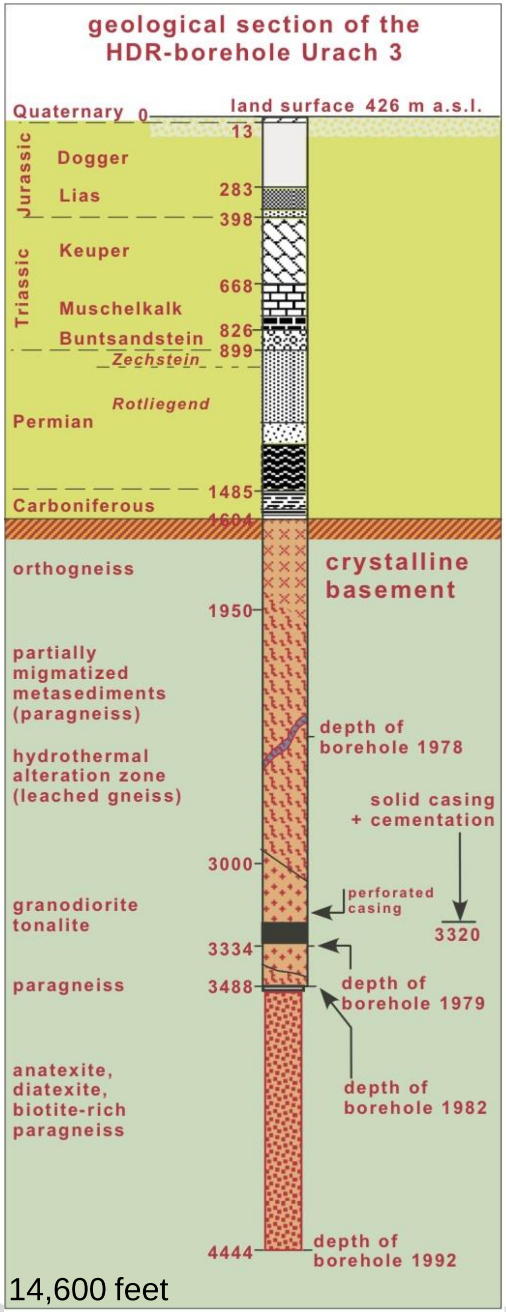
Permeability seems to decrease with depth:

$\log \kappa = -1.38 \log z - 15.4$

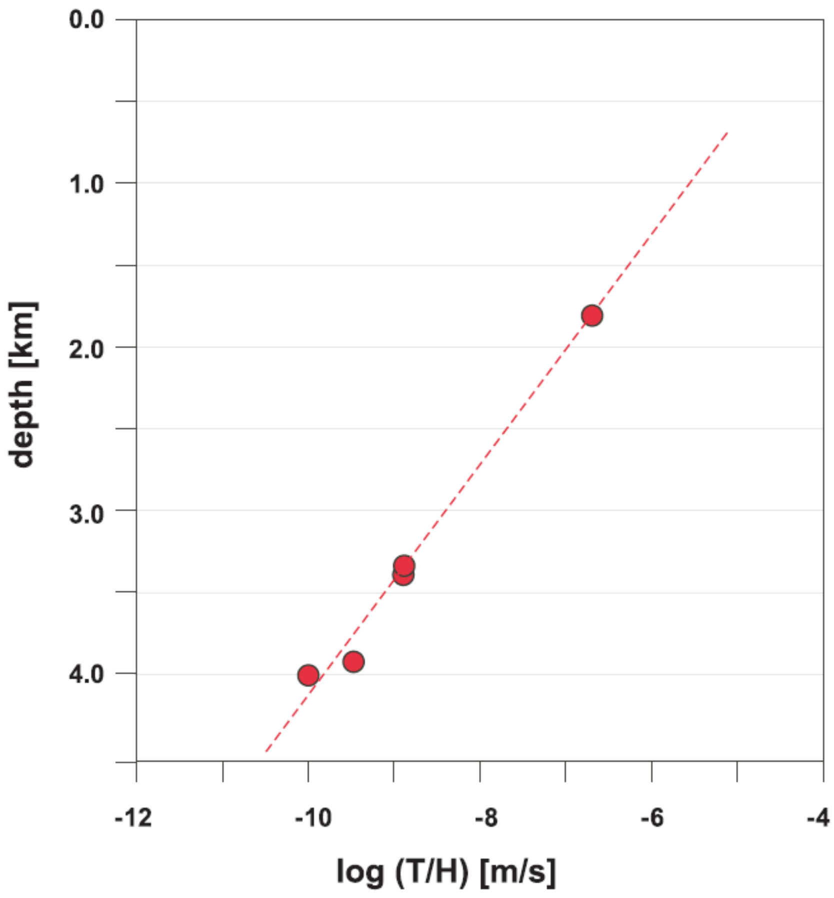
with: κ (m²) – permeability
z (km) - depth



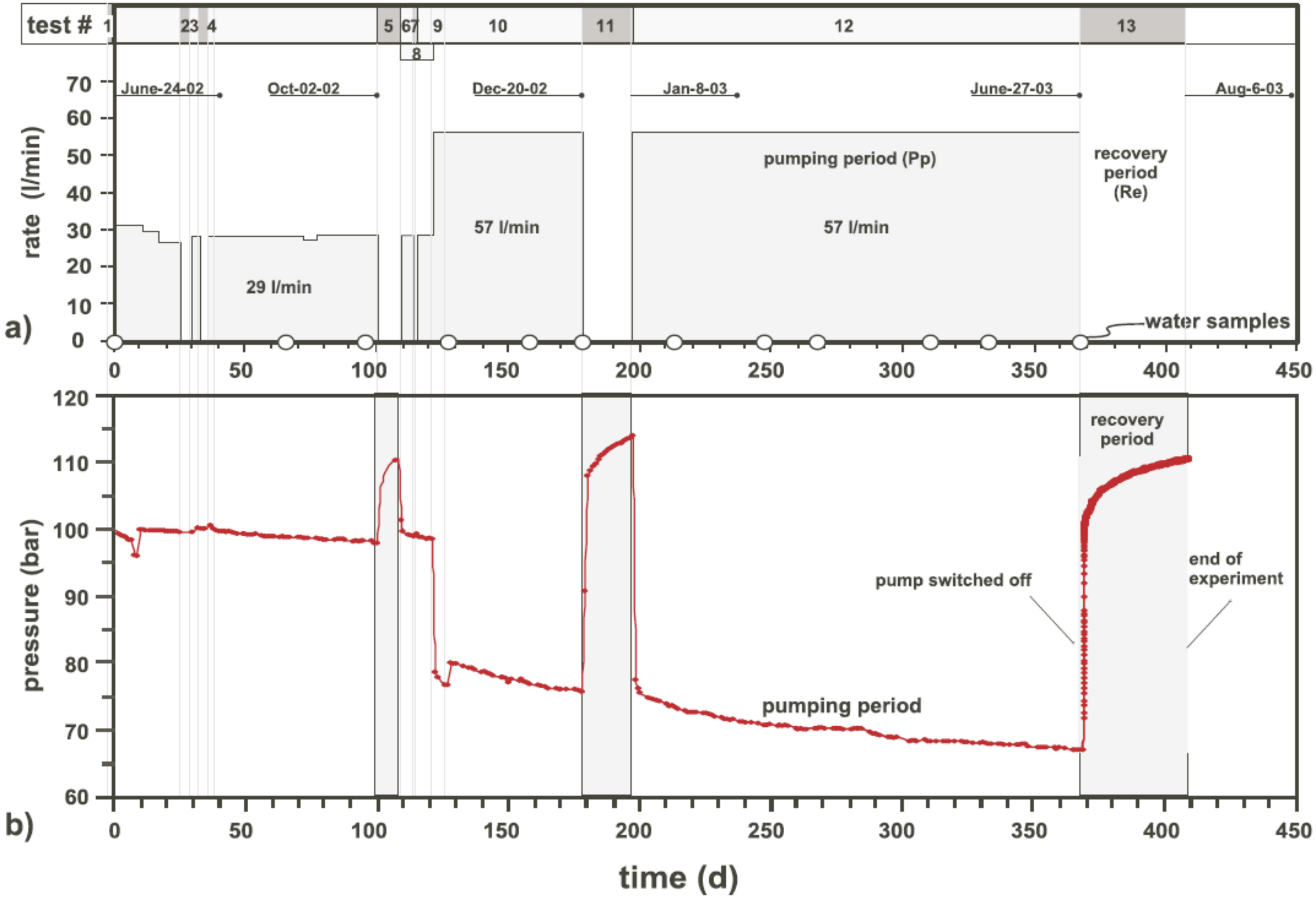




Decrease of hydraulic conductivity with increasing depth in the crystalline basement of the Urach borehole



Water conducting fractures are interconnected with each other over large areas

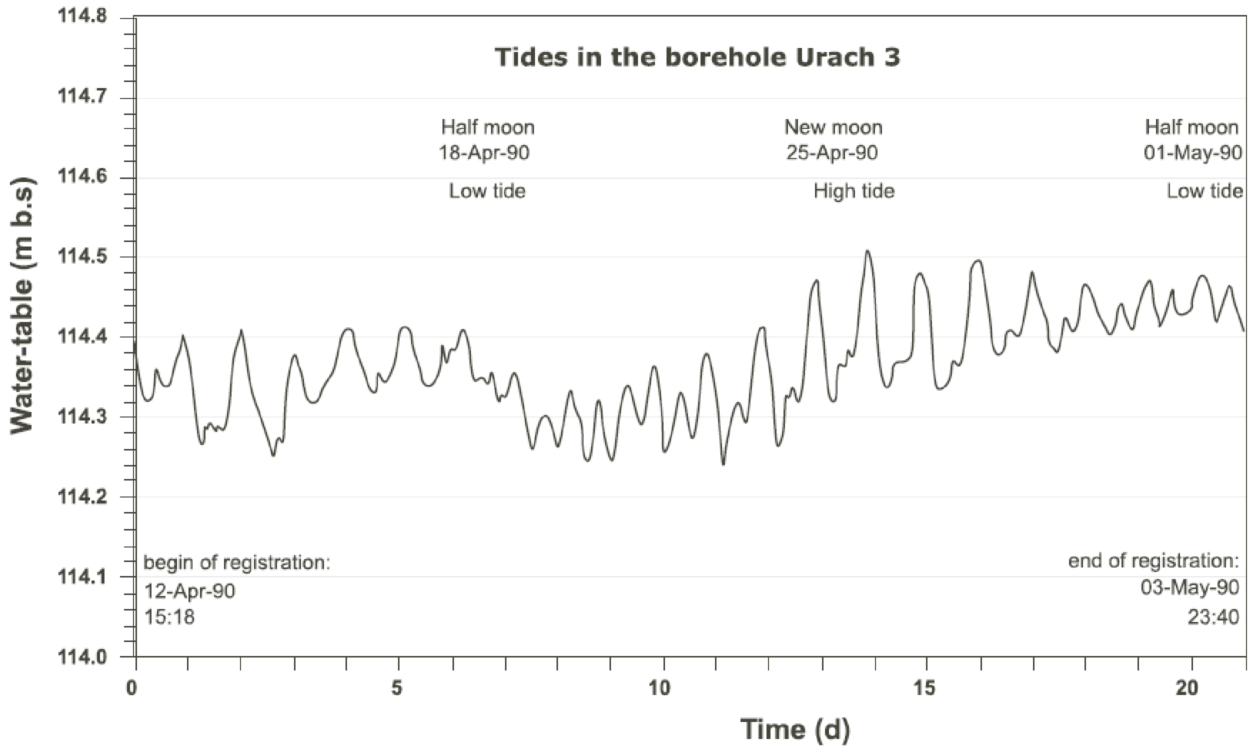


Long-lasting pumping-tests, KTB-site, 4 km depth:

- **rate ± 1 l/s**
- **1 year**
- **TDS constant**

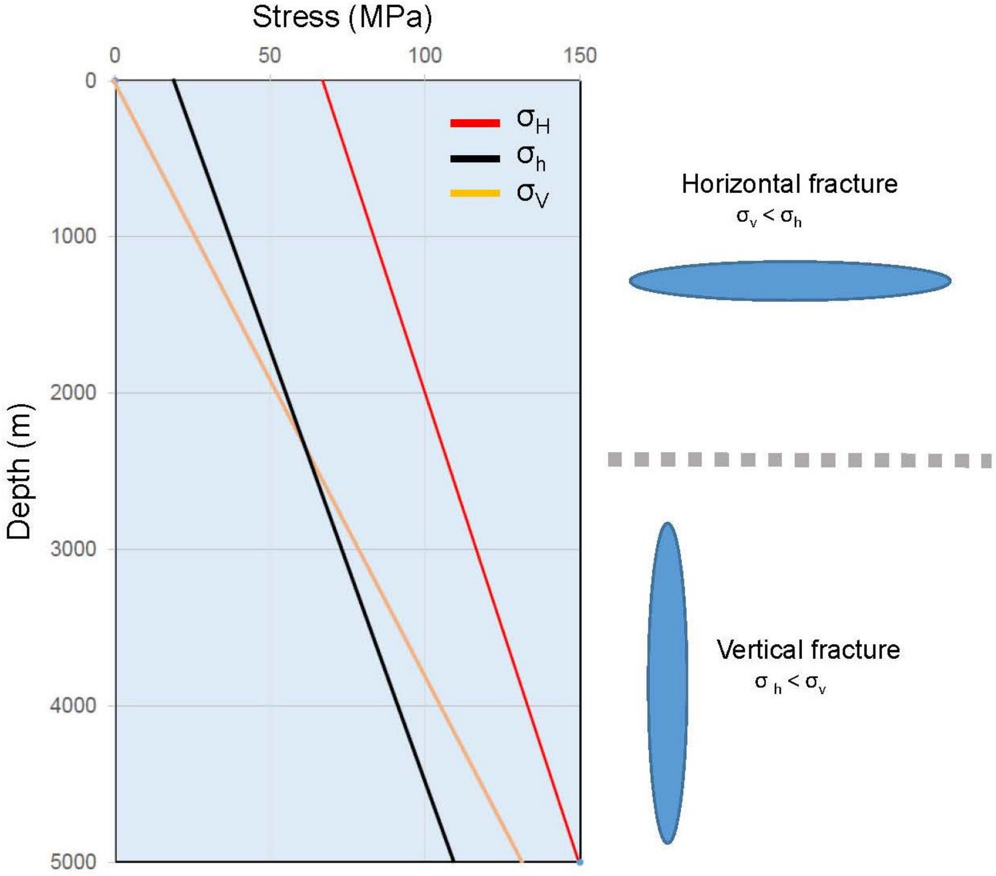
Water conducting fractures are interconnected with each other over large areas

Rise and fall of the Earth surface 2 times per day (earth-tides), causes fluctuations of water table in deep boreholes due to compressibility, on the order of up to 18 cm. Pore space in crystalline basement is very low, so, a huge volume of interconnected pore space in fractures reacts.



Change of fracture-orientation with depth
Deep circulation-systems

With increasing depth, open fractures tend to be <u>vertically orientated</u>, because vertical pressure increases stronger than horizontal pressure.



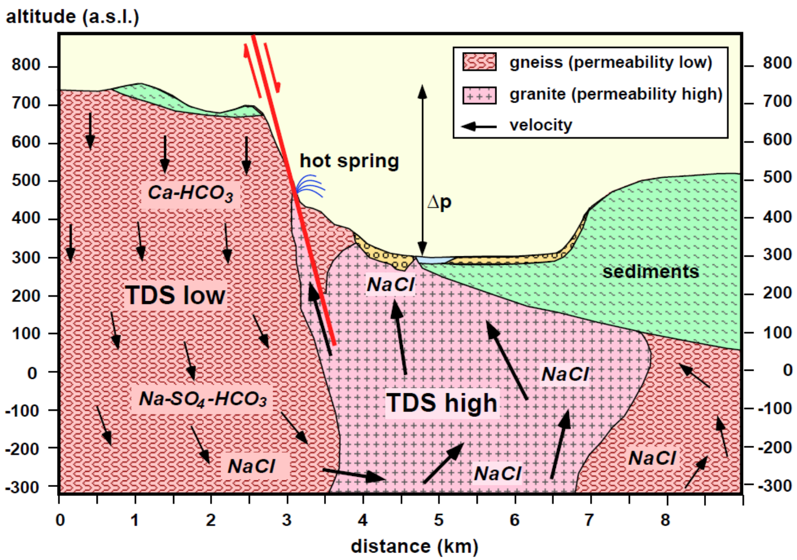
after: Brown & Hoek 1978,
Valley & Evens 2003

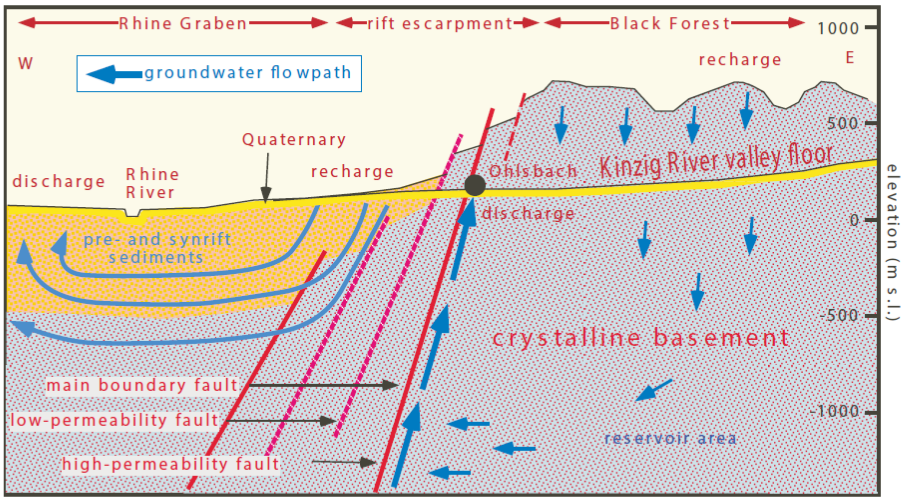
Deep circulation-systems
Topographic gradient needed (= motor for water flow)

The occurrence of predominantly <u>vertical fractures</u> in the depth favors deep circulation systems:

- thermal springs
- upwelling of saline water (± constant TDS)

It shows, that the open water conducting fractures are interconnected with each other over large areas





Without topographic gradient, no circulation-systems!

No topographic gradient present & decreasing water table with depth

→ **motor for water flow = depletion of water in depth possibly due to water 'consumption' because of WRI (alteration)**

silicate mineral + H_2O-rich solution (low TDS) ⇒
residual hydrous minerals (zeolite, clay, quartz) + H_2O-depleted solution (high TDS)

The 'consumption' of the pore water leads to:

1. **evolution of highly saline brines**
2. **precipitation of solids including zeolite**
3. **reduction of pore space (permeability)**
4. **decreasing water table with depth, e.g. hydraulic gradient**
5. **Flow of low TDS-water via fractures from above (± vertical fractures)**

Stagnant fluids, an unrealistic concept

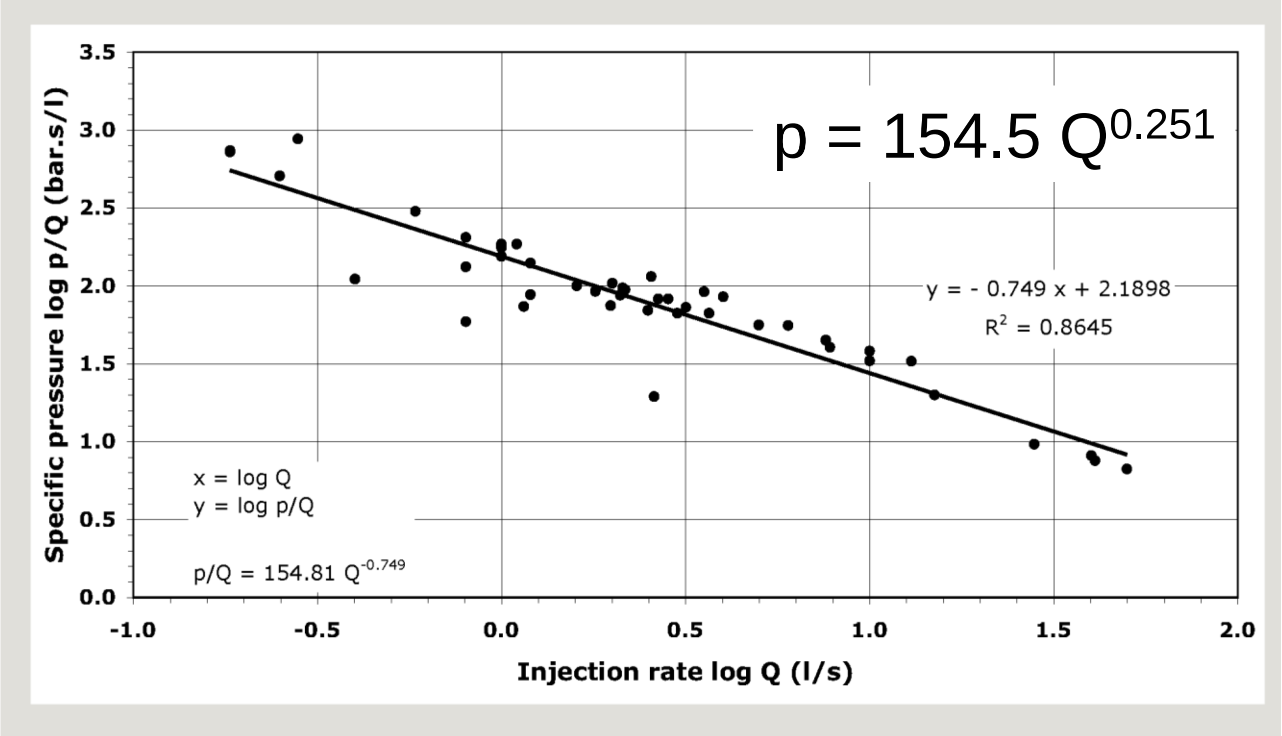
So, fluids in the Upper Continental crust are not just stagnant:

In areas with topography we observe deep circulation systems, origin of thermal springs.

Earth-tides will keep fluids in motion and exchange, to keep them chemically active due to fluid exchange, so that WRI continues.

Permeability changes in time

- WRI (relatively slow)
- earthquakes (rapid)
- artificially, e.g. injection-tests



Elastic reaction of the rock: fractures are widened

$$w = 8.14\ 10^{-7} / Q^{-2.50}$$

Lack of shear stress, rock reacts elastically with no significant permanent increase in permeability. If shear stress is present: increase in permeability may result.

Summery / Conclusions

- large variability in permeability in the upper 100 m
- decrease of permeability with increasing depth
- interconnected open fracture-system over large areas
- with increasing depth fractures tend to become vertical

- topographic gradient: deep circulation, thermal springs, vertically oriented fractures in depth,
- no topographic gradient: decreasing water table with depth, ‘consumption’ of water (WRI), vertically oriented fractures in depth,

- fluids in the Upper Continental Crust are not stagnant (earth-tides, deep circulating systems)
- permeability is changing in time (WRI, earthquake, man-made)

Thank you very much for your interest!

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für Umwelt, Naturschutz
und Reaktorsicherheit