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 $\kappa$ [m$^2$], fluid parameters ($\rho$, $\mu$) 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 large variability in permeability (several log-units), with highest values similar to those of gravel-aquifers.

In highly deformed areas granites seem to be more permeable 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: $\kappa$ (m$^2$) – permeability
$z$ (km) - depth

K = $\kappa \rho g/\mu$
Decrease of hydraulic conductivity with increasing depth in the crystalline basement of the Urach borehole

![Decrease of hydraulic conductivity with increasing depth in the crystalline basement of the Urach borehole](image)
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 *vertically orientated*, because vertical pressure increases stronger than horizontal pressure.

![Graph showing stress vs. depth with different fracture orientations and stress lines.](image)

*Horizontal fracture: $\sigma_v < \sigma_h$*

*Vertical fracture: $\sigma_h < \sigma_v$*

*Graph data sources: Brown & Hoek 1978, Valley & Evens 2003*
Deep circulation-systems
Topographic gradient needed (= motor for water flow)

The occurrence of predominantly vertical fractures 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 + H₂O-rich solution (low TDS) ⇒
residual hydrous minerals (zeolite, clay, quartz) + H₂O-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

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!