Reaction Veins and the Permeability of the Continental Crust

Kurt Bucher & Ingrid Stober

University of Freiburg &
Karlsruhe Institute of Technology KIT
Germany

bucher@uni-freiburg.de

Evidence for fluid flow in the upper crust

What do reaction veins tell us about the permeability of the crust?

Serpentine veins in peridotite

Olivine + H_2O ➜ Serpentine ± solutes

Reactive fluid flow (viscous flow)

Symmetrical veins

Central suture

Age hierarchy of fracture porosity

Fracture porosity ➜ permeability

Permeability is a complex function of time

Darcy Flow Model

$$\vec{q} = -[K]\ \frac{1}{g\rho} \nabla P$$

Reaction veins in metamorphic rocks require viscous flow of reactive fluid (liquid, aqueous fluid)

Viscous flow in porous media can be modeled in certain environments with a linear flux – force equation: Darcy Flow model

Transport models (e.g. Darcy Model) derive values for transport coefficients. K = hydraulic conductivity (m s^{-1}). Permeability κ (m^2) relates to K = $\kappa \cdot g \cdot [\rho / \mu]$ (fluid properties)

Reaction veins tell us that κ and K are strongly time dependent

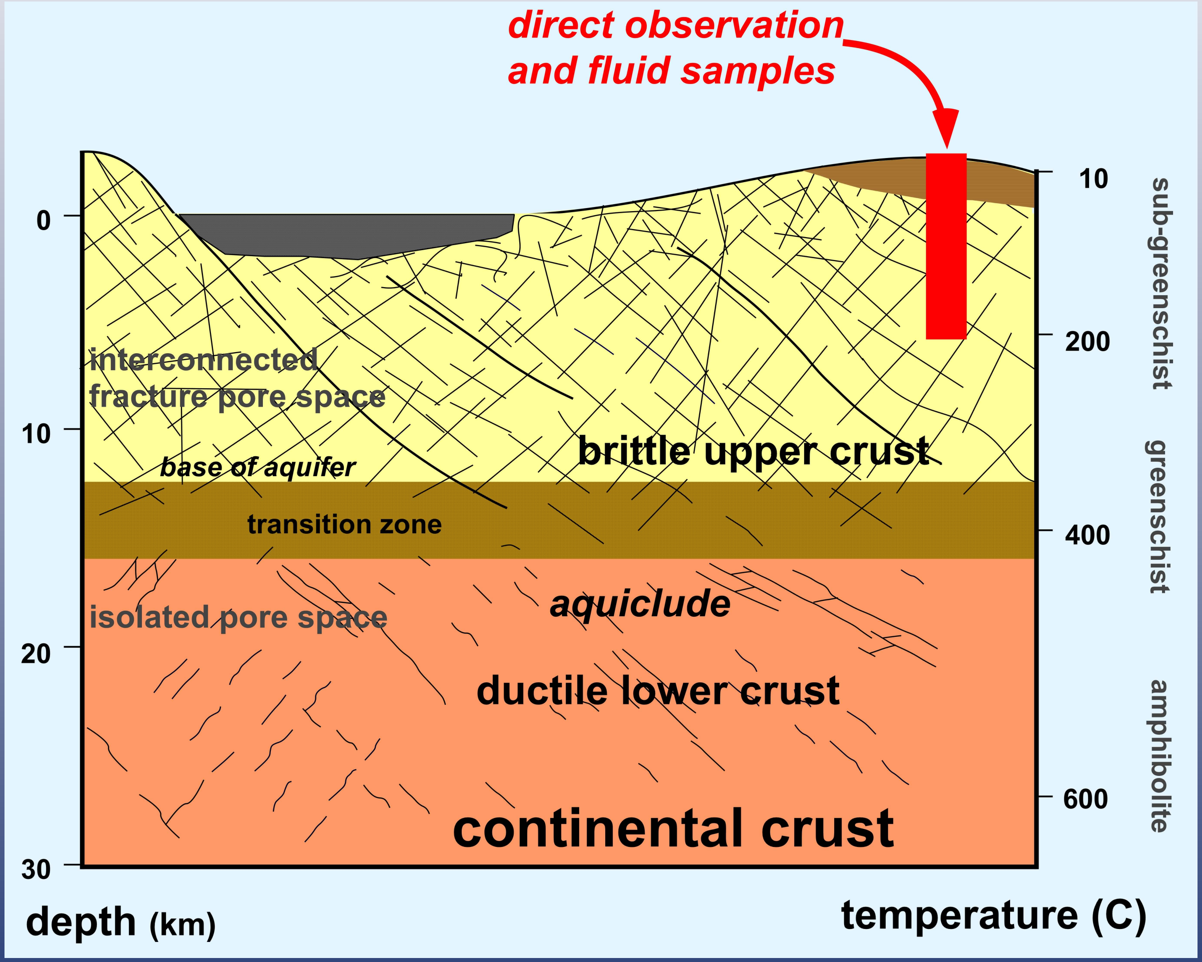
Fluid Flow in the Crust

where do reaction veins occur in crust?

related to fracture prorosity transport described by Darcy law

in brittle upper crust above brittle – ductile transition zone (BDT)

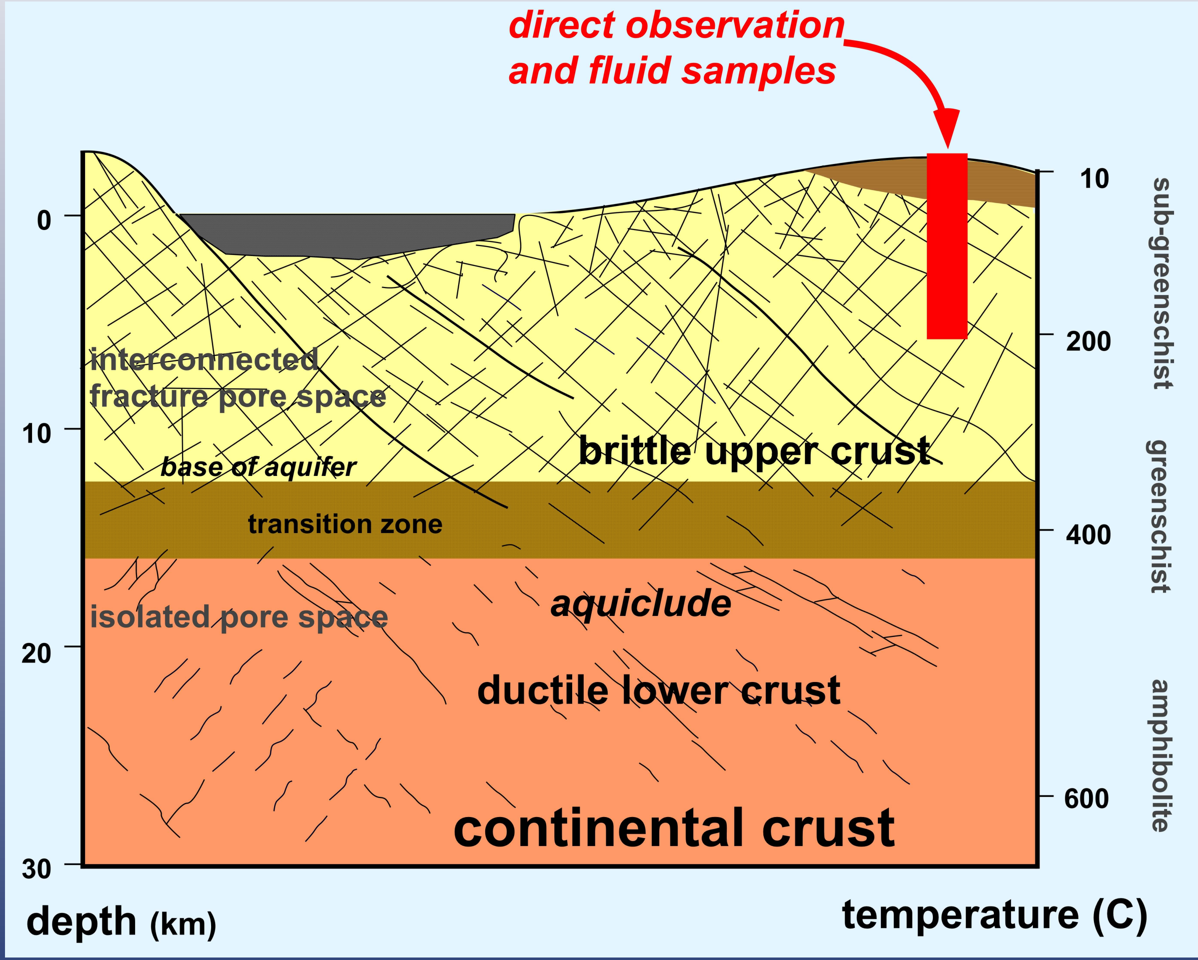
to ~ 5 km depth transport coefficients (permeability) has been derived from hydraulic well tests



Fluid Flow in the Crust

prominent reaction veins occur between 5 and BDT

They reflect porosity, fluid flow and permeability structure of the lower part of the upper crust and its variation with time



Temperature range 200 – 450 ˚C

Reaction Veins in the Crust – some Examples

Open talc veins in peridotite

Olivine **+ H_2O +**
SiO_{2aq} = Talc

The veins formed at 350˚C and are not sealed

Contribute to flow porosity from the time when they formed until today

Flisarvatnet, Norwegian Caledonides

Reaction Veins in the Crust – some Examples

Reactive fluid flow converts green dolerite rock to brown albite – carbonate rock

The veins formed at 300˚C and are sealed with late (calcite)

Fractures contributed to flow porosity at the time when they formed.

Today fractures are sealed (or partly sealed) with calcite

reaction veins in 2.2 Ga dolerites, Vannøya, West Troms Basement complex, Norway

Reaction Veins in the Crust – some Examples

Sealed serpentinite veins in peridotite
Olivine **+ H_2O + SiO_{2aq}** = Serpentine

The veins formed at 300˚C and are sealed

Contributed to flow porosity at the time when they formed

Today the veins are not fluid conducting structures

Erro-Tobbio, Voltri Group, Genova Italy

Reaction Veins in the Crust – some Examples

Epidote – chlorite veins in gneiss (typical continental crust)

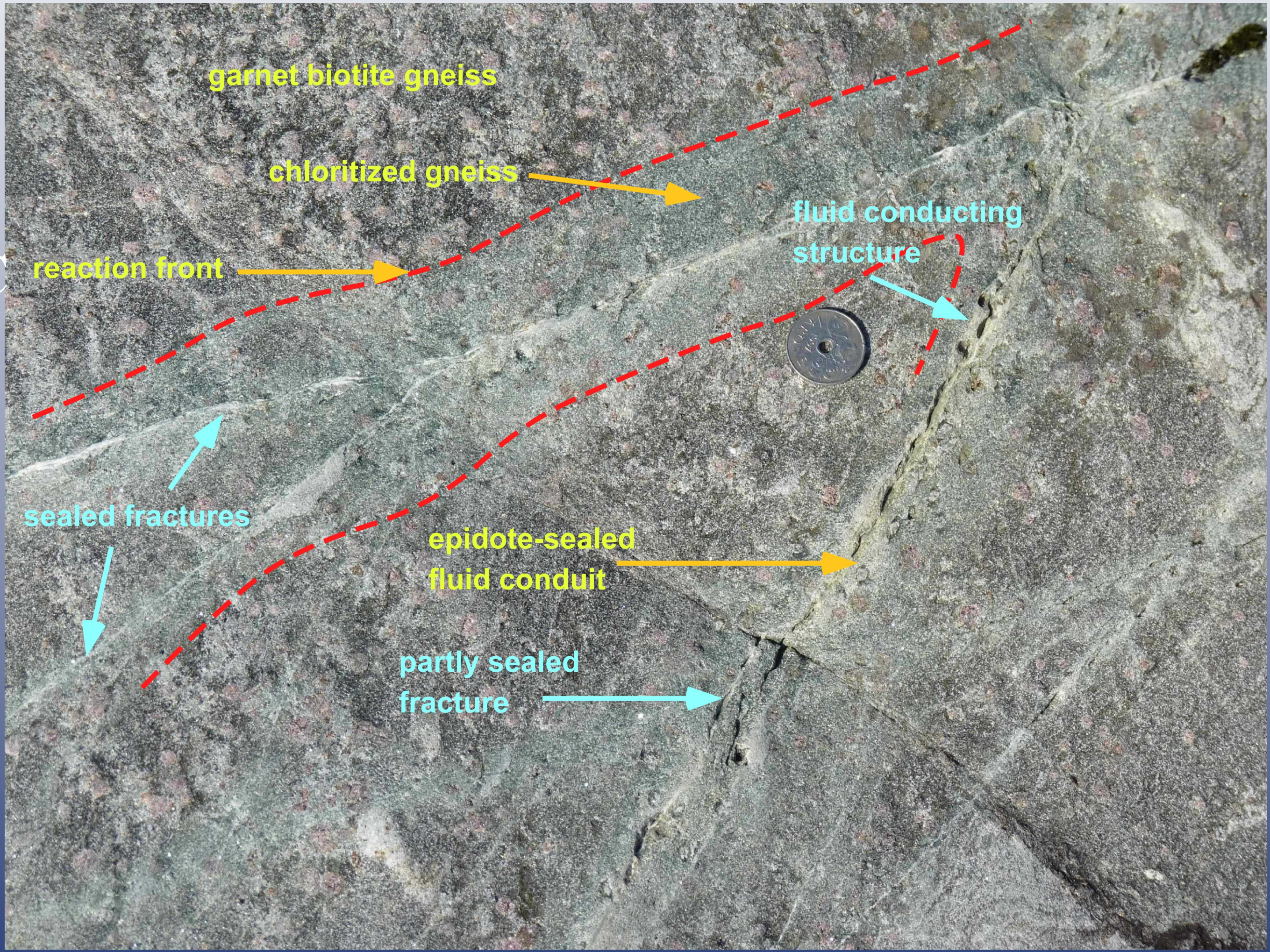
The veins formed at 300˚C

Some of the veins and fractures are sealed, some fractures are open

Different generations of fractures

Contributed to flow porosity at the time when they formed

Today some fractures are fluid conducting structures



Brensholmen, West Troms Gneiss Complex, N-Norway

Reaction Veins in the Crust – some Examples

Tremolite-calcite vein in dolomite marble

Olivine-calcite vein in dolomite marble

The veins formed at 400 and 450 °C resp.

All of the veins and fractures are sealed

Different generations of fractures

Contributed to flow porosity at the time when they formed

Today none of the fractures are fluid conducting structures

Bergell Contact aureole, Val Sissone, Italy

Reaction Veins in the Crust – some Examples

Propagation of reaction front

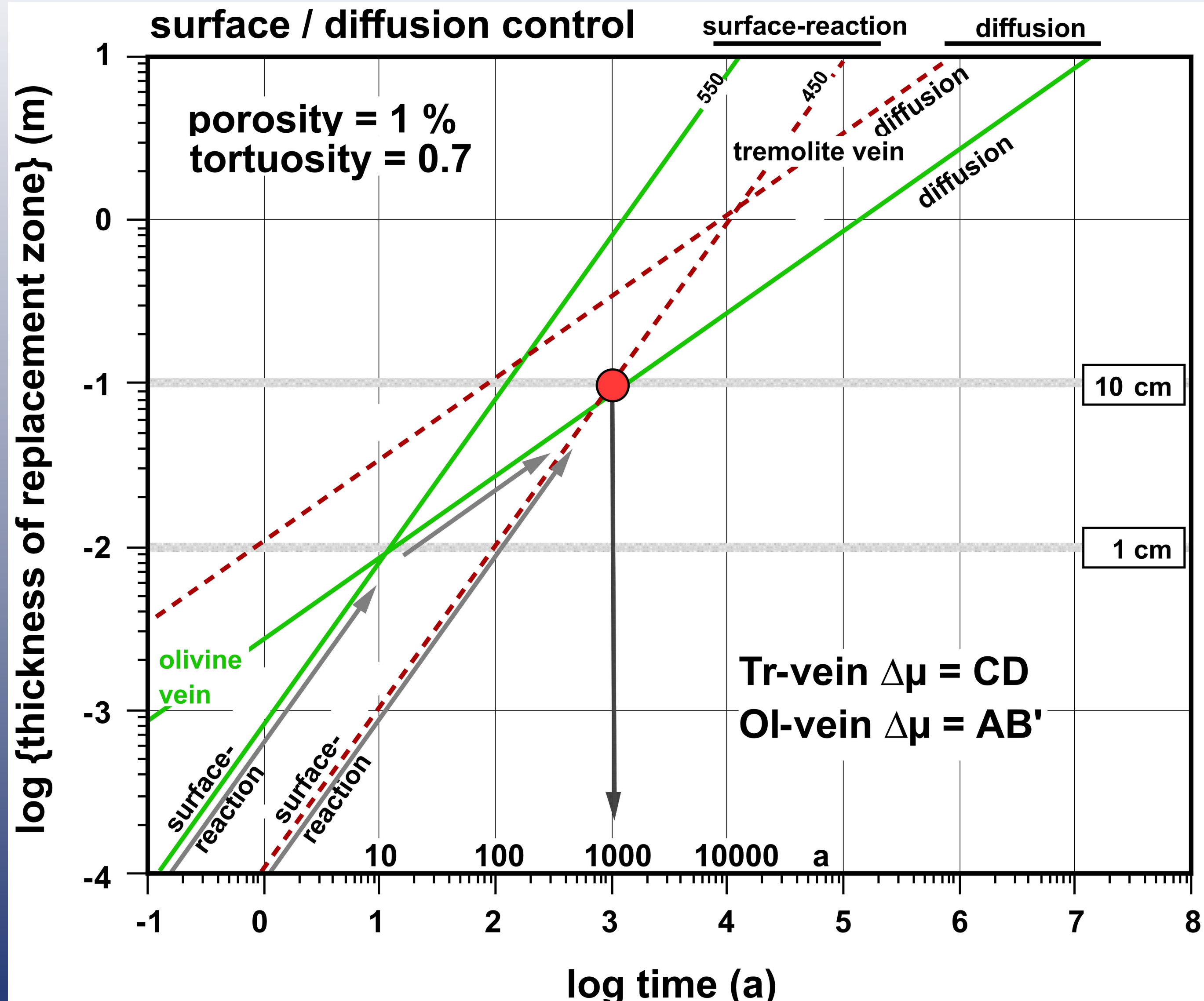
Transport vs. reaction kinetics

Olivine veins = transport controlled

Tremolite veins = reaction controlled

Fluid flow in open fracture (suture)?

Permeability (evolution)?



Bucher, K., 1998, Growth mechanisms of metasomatic reaction veins in dolomite marbles from the Bergell Alps. Mineralogy and Petrology, 63, 151-171.

Reaction Veins in the Crust – some Examples

Tremolite-calcite veins in dolomite marble

The veins formed at 400 °C
All of the veins and fractures are sealed

Different thicknesses of veins indicate different reaction time and different volumes of reactive fluid

Contributed to flow porosity at the time when they formed

Bergell Contact aureole, Val Sissone, Italy

Reaction Veins in the Crust – some Examples

Tremolite-calcite vein in dolomite marble

The vein formed at 400 ˚C
The vein and fractures are sealed

Strike – slip fractures show no evidence for reactive fluid flow (no veins)

Fracture with extension structure developed a reaction vein

Bergell Contact aureole, Val Sissone, Italy

Reaction Veins in the Crust – some Examples

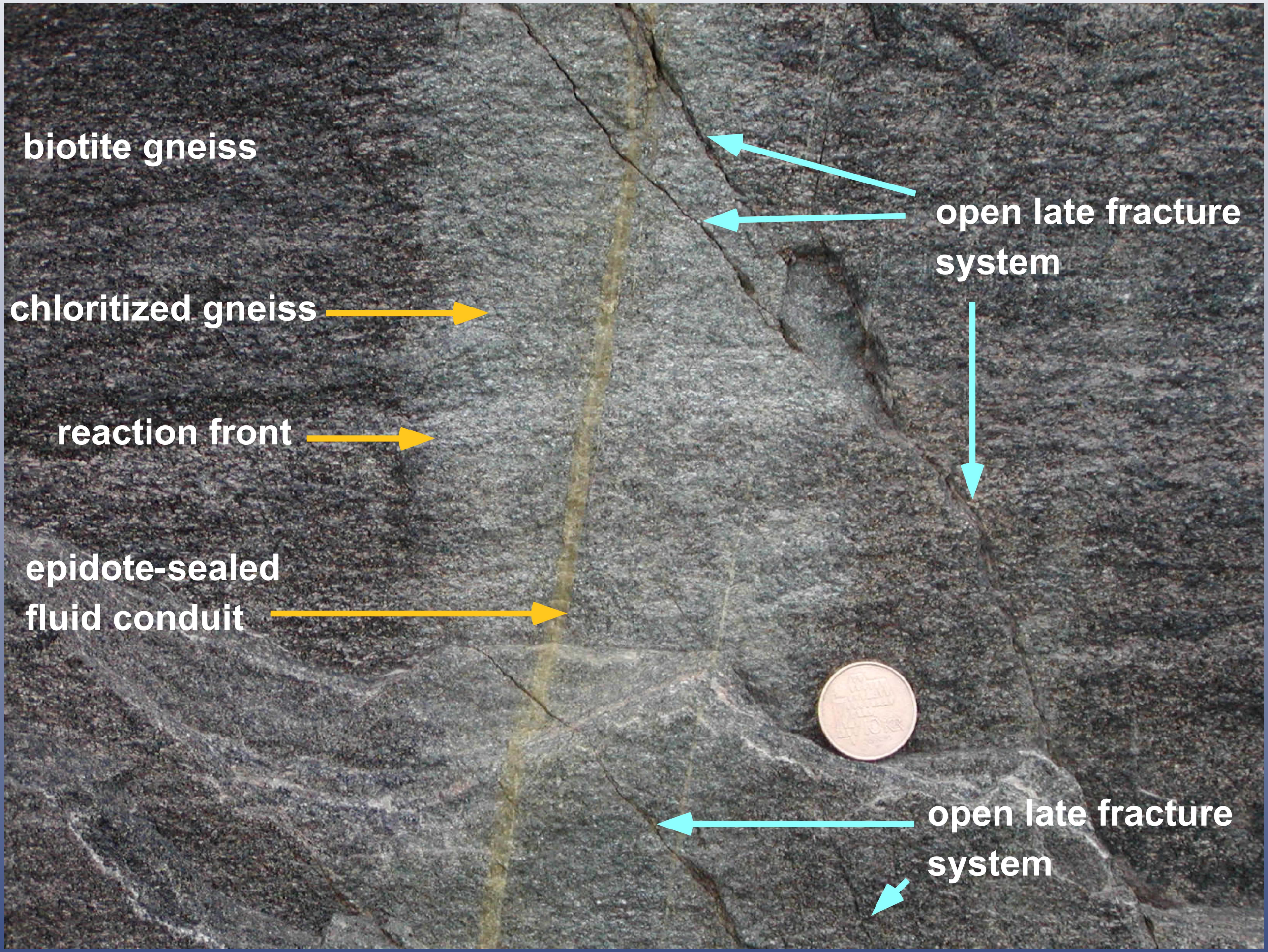
Epidote – chlorite veins in gneiss (typical continental crust)

The veins formed at 300˚C
Some of the veins and fractures are sealed, some fractures are open

Different generations of fractures

Contributed to flow porosity at the time when they formed

Today some fractures are fluid conducting structures



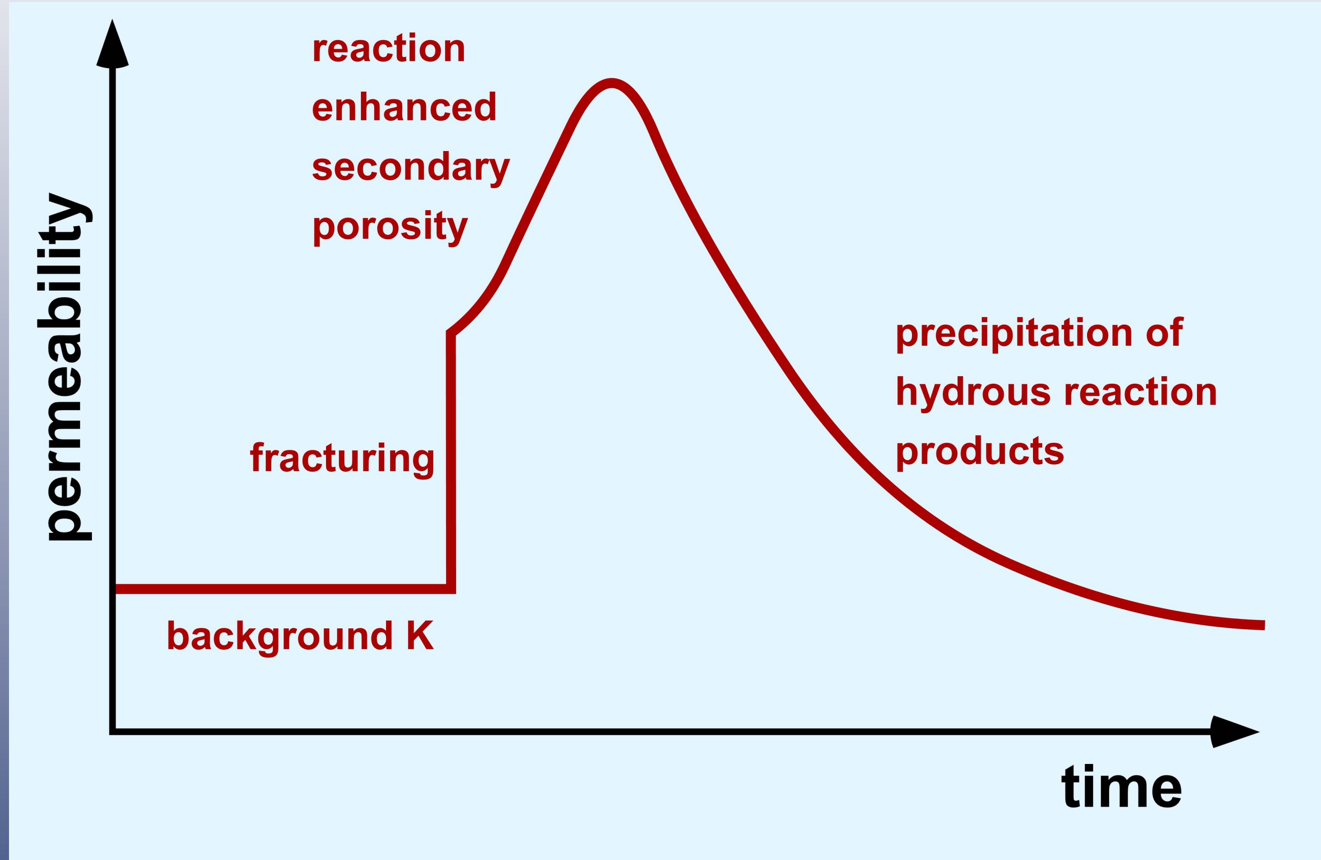
Hammerfest, Kalak nappe, N-Norway

Permeability of Continental Crust

What can we learn from the reaction veins?

Reaction veins form from reaction of fluid with rock (fluid must be reactive). Veins are linked to the permeability of the crust

Fractures create flow porosity for reactive fluids



Fluid-rock interaction first creates permeability then it destroys permeability

The typical permeability versus time evolution for a single fracture relates with the fracturing – time relationship of a crustal volume to a general permeability versus time evolution

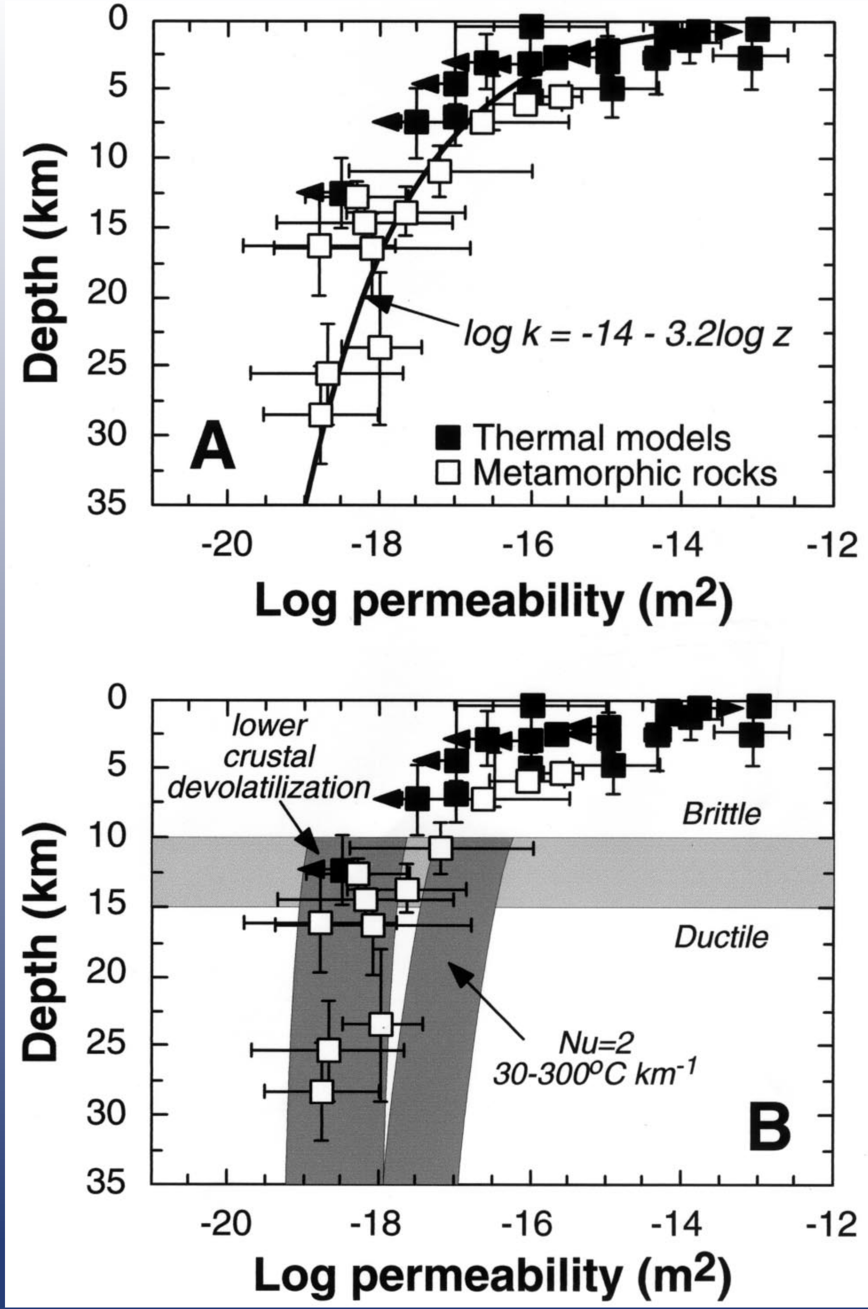
Permeability of Continental Crust

permeability ranges from -18 to -13 m^2 in the brittle upper crust

lower crustal devolatilization refers to a short lived process during an orogenic active period of the crust.

the permeability of normal "cold" inactive crust is not defined

Normal "cold" lower crust is fluid absent and thus concepts of viscous flow, permeability and flow laws are inappropriate for normal environments

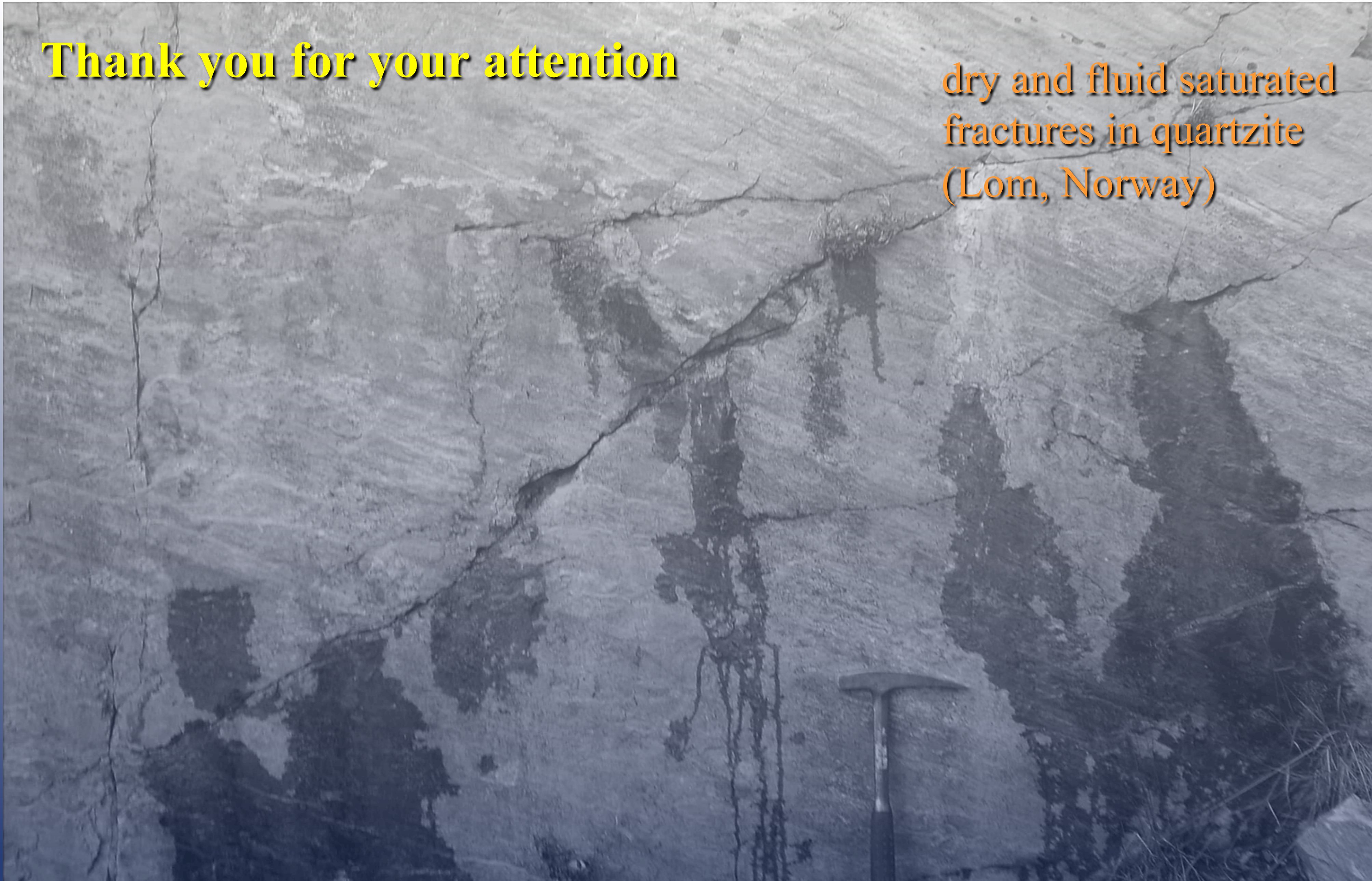


Manning, C. E. & Ingebritsen, S. E., 1999. Permeability of the continental crust: Implications of geothermal data and metamorphic systems. *Reviews of Geophysics*, **37**, 127-150.

conclusions

- reaction veins testify reactive fluid flow in the brittle crust
- reaction veins show that flow porosity (permeability) is often transient
- reaction veins indicate that fluid flow (permeability) requires extension
- reaction veins demonstrate that different generations of fluid conducting structures contribute to permeability at different times
- reaction veins confirm that fluid flow and related permeability can only be recorded in reactive systems (in geologically active areas)

Thank you for your attention



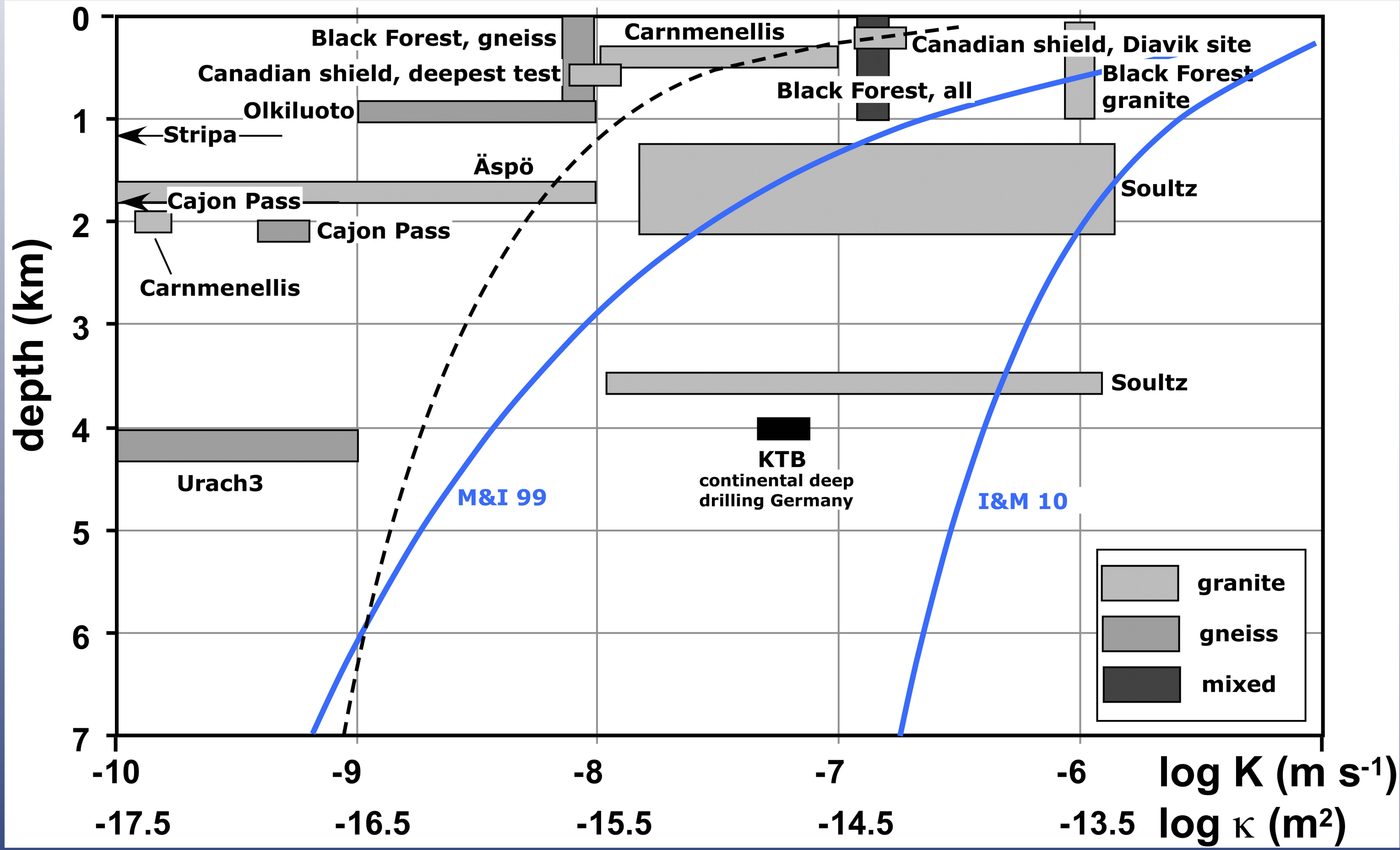
dry and fluid saturated fractures in quartzite (Lom, Norway)

Permeability of Continental Crust

permeability ranges over 9 log units

from -21 to -12

permeability κ (m^2) depends on the geologic structure and the history of a volume of continental crust



Permeability of Continental Crust

range of crustal permeability down to BDT
-17 to -12 m^2

below BDT permeability estimates are based on short lived metamorphic fluid generating dehydration pulses

distinguish normal inactive continental crust from orogenic belts (fossil or active) and rifts and other active systems

this study = Ingebritsen & Manning 2010 Geofluids