Laboratoire de
Géologie

Permeability of cracked rocks and glass

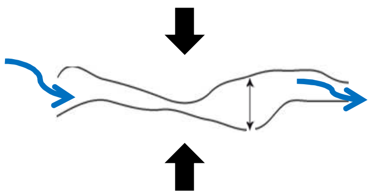
Yves GUEGUEN,
Jérôme FORTIN
Audrey OUGIER-SIMONIN

Permeability in the upper crust

- **Basaltic ocean crust permeability decrease from near surface values (100 mD) to low values (< 0.1 mD) at 1km and deeper (Fisher, 1998)**

- **From log data, evidence of crack networks (Violay, 2010)**

- **Permeability-depth variation can be interpreted by crack closure (low T conditions, no sealing)**



→ Cracks play a major role

Low permeability rocks under confining pressure

Reference	Rock type (low porosity rocks)	a, 10^{-2} MPa^{-1}	P^* = a^{-1}, MPa
YALE (1984)	tight sandstones	3.8 - 6.3	15.9 - 26.3
BRACE *et al.* (1968)	Westerly granite	3.3	30.6
BERNABE (1986)	Chelmsford granite	2.9	34.6
	Barre granite	2.3	42.7
FISHER and PATERSON (1992)	Carrara marble	4.7	21.3
HUENGES and WILL (1989)	Urach gneiss	4.9	20.4
MORROW *et al.* (1994)	gneiss [Kola]	3.2	31.2
	basalt [Kola]	10.2	9.8
	amphibolite [KTB]	5.8 -11	9.1 - 17.2

$$k = k_o e^{-aP}$$

→ Cracks ?

$10 < P^* < 40$ (MPa)

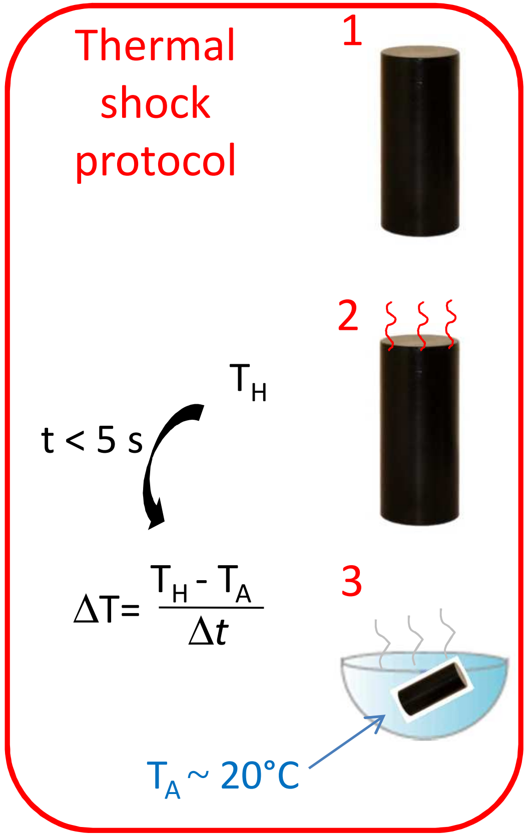
An absolute reference: glass + cracks

Low permeability rocks : cracks ?

An ideal case: intact synthetic glass with cracks

How to introduce cracks in glass samples ?

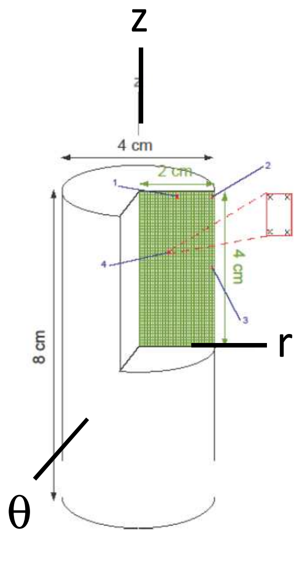
- *thermal shock*
- *cracks only*

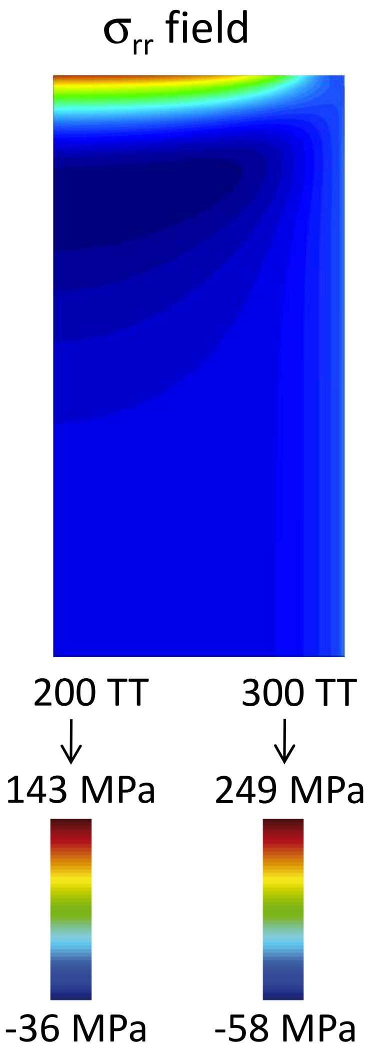


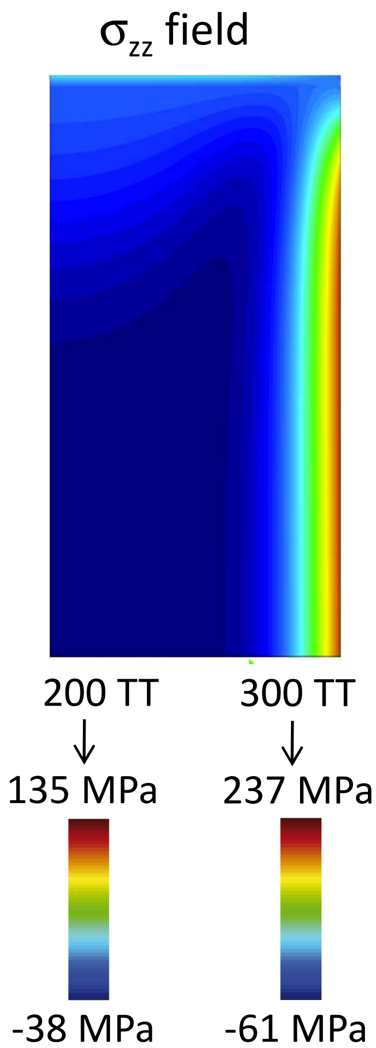
T_H = 100, 200 and 300°C

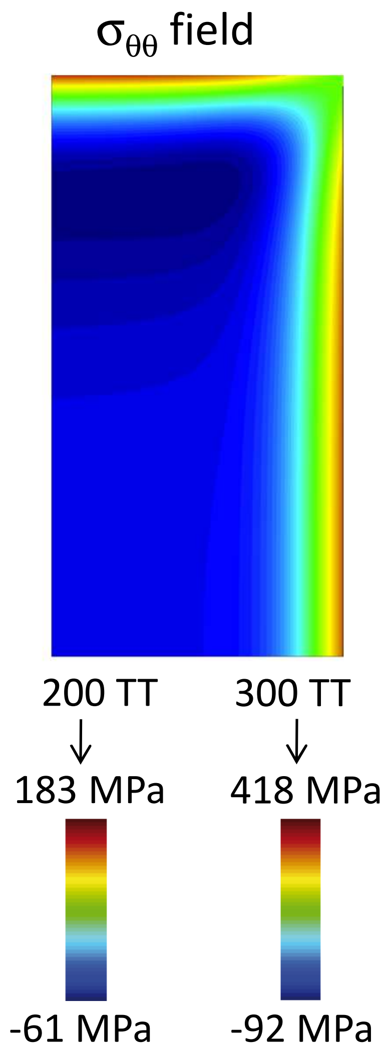
Shocked glasses: temperature and stress distribution

t = 20s after thermal shock



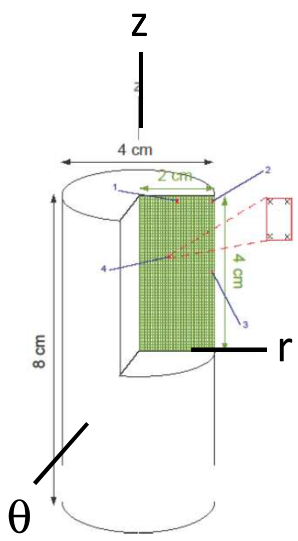






Shocked glasses: temperature and stress distribution

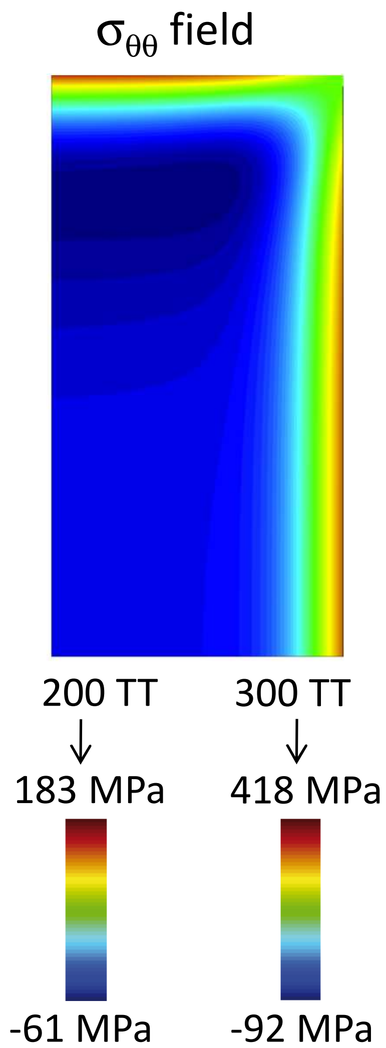
t = 20s after thermal shock



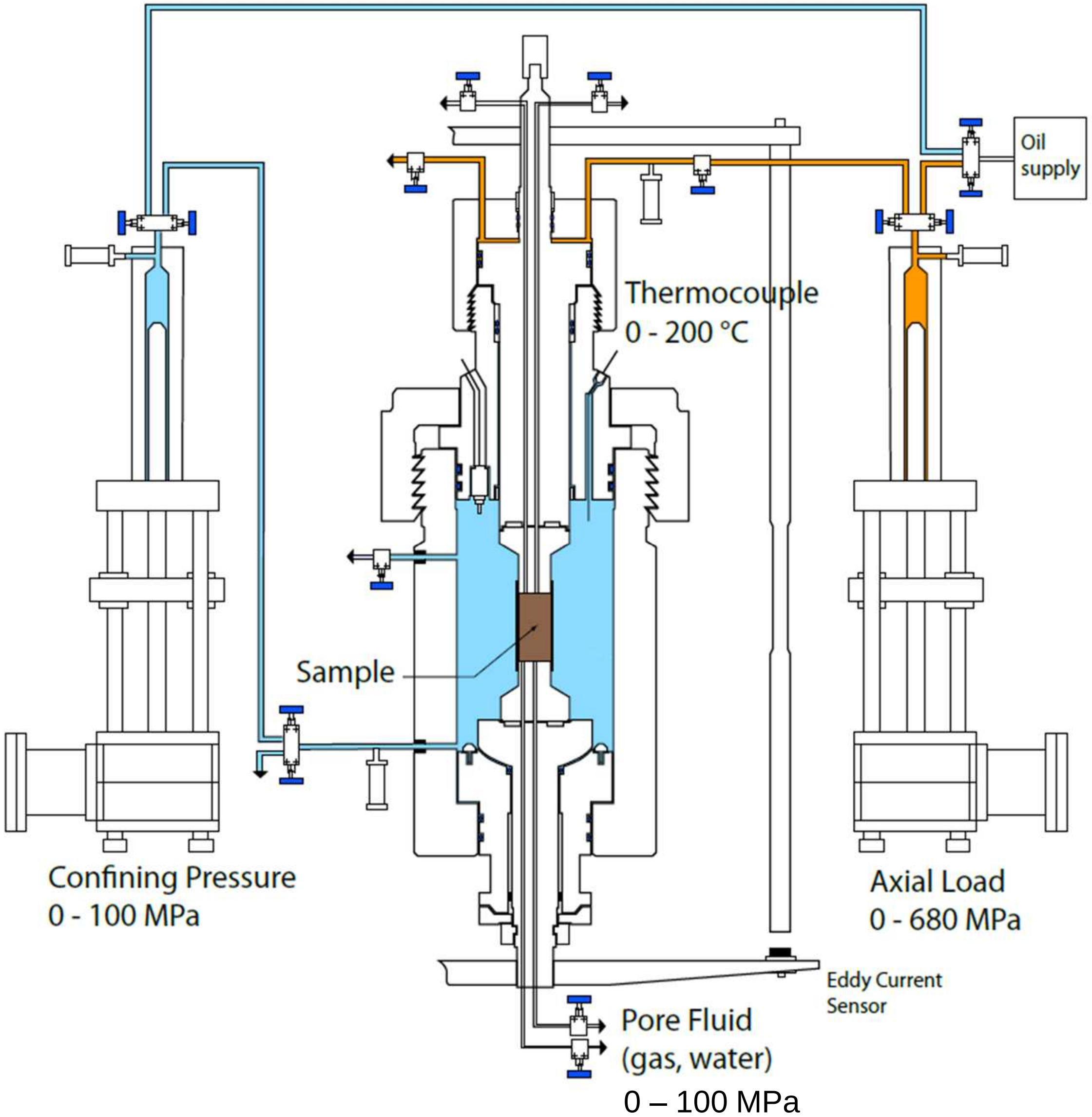
Outward ring : in traction

Inner core: in compression

→ Mostly vertical cracks in the outward ring



Triaxial cell apparatus: Measurement of V_P, V_S, k

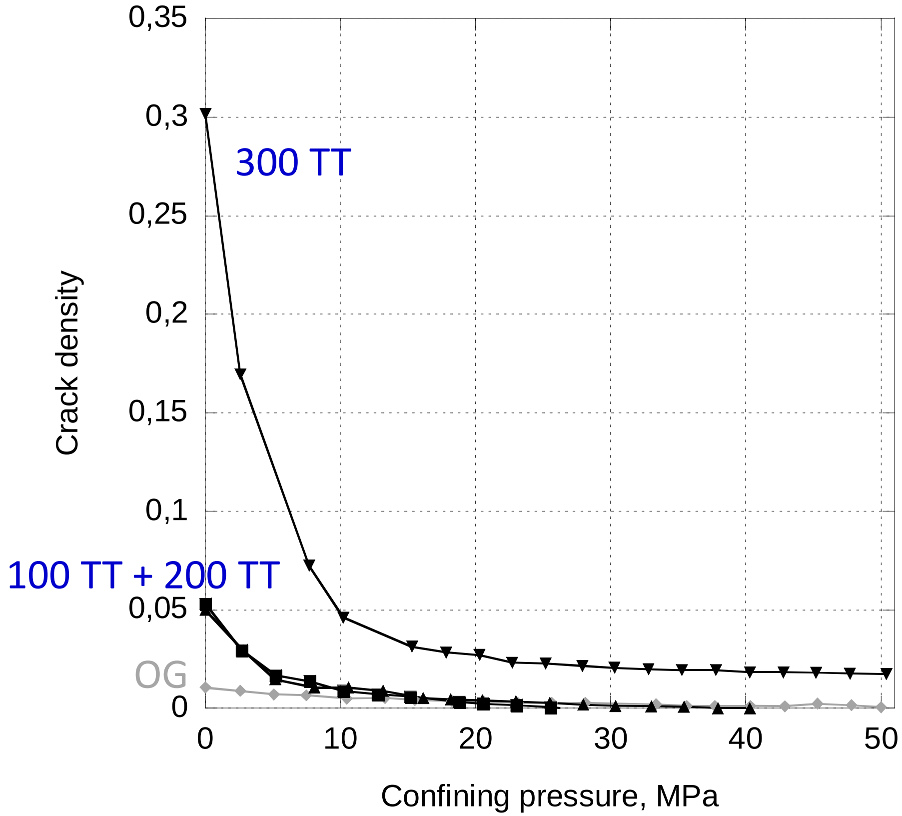


Crack density (from Vp, Vs) variation with pressure

Crack density is obtained from elastic moduli K and G (Vp and Vs)

$$\begin{cases} \dfrac{K_o}{K} = 1 + \rho_c \dfrac{h}{1-2\nu_o}(1-\dfrac{\nu_o}{2}) \\ \dfrac{G_o}{G} = 1 + \rho_c \dfrac{h}{1+\nu_o}(1-\dfrac{\nu_o}{5}) \end{cases}$$

Crack aspect ratio ξ



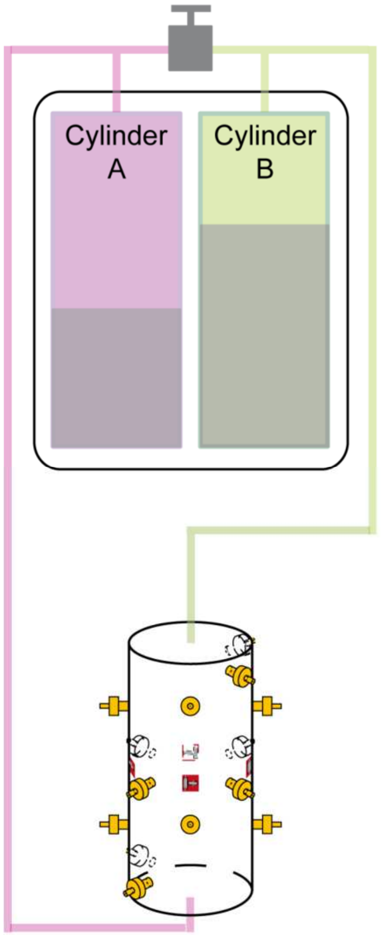
➡ Crack closure:

at $P_{hydro} \approx$ 15 MPa for shocks at 100 and 200 °C

at $P_{hydro} \approx$ 40 MPa for shock at 300°C

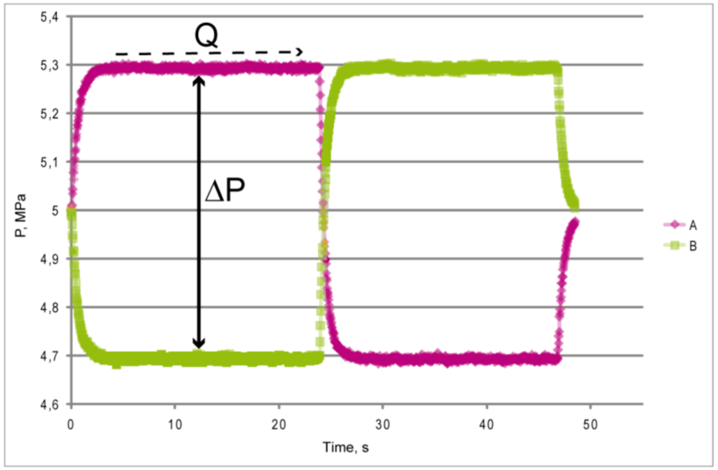
→ ξ ~ 10^{-3} to 10^{-4}

Methods of measurements of permeability



300 °C samples

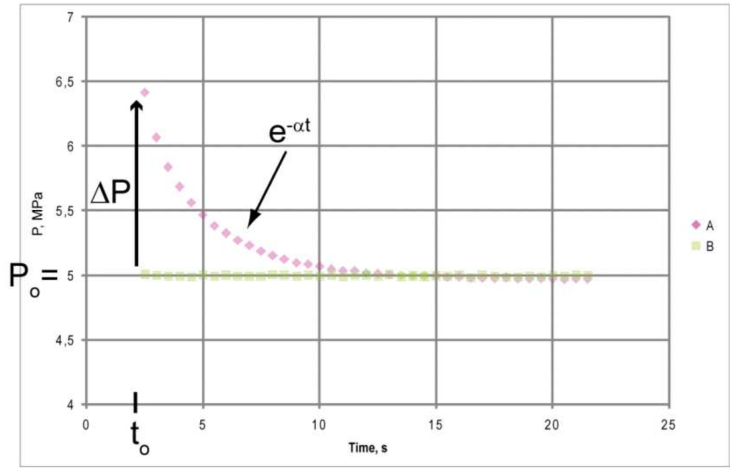
a) Constant flow method



➡ P_{eff} <10 MPa

Darcy's law: $k = \dfrac{Q}{\Delta P}\dfrac{L}{A}\mu$

b) Pulse decay method (1/2-pulse)



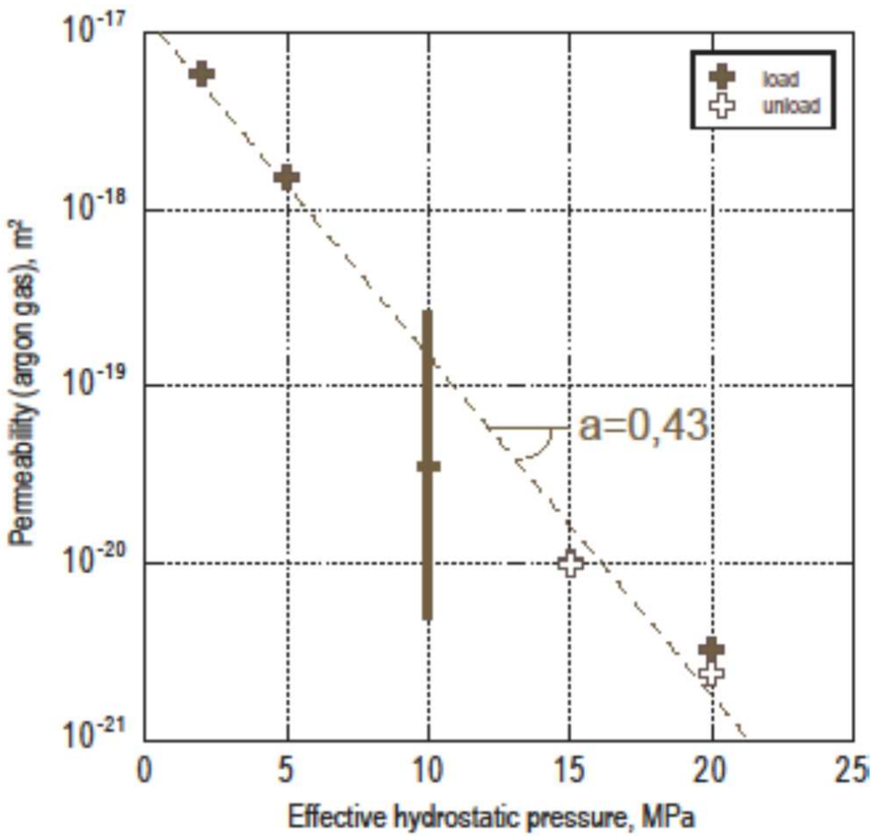
➡ $P_{effective} \geq 10$ MPa

$$k = \alpha\beta\frac{L}{A}\mu V_{pulse}$$

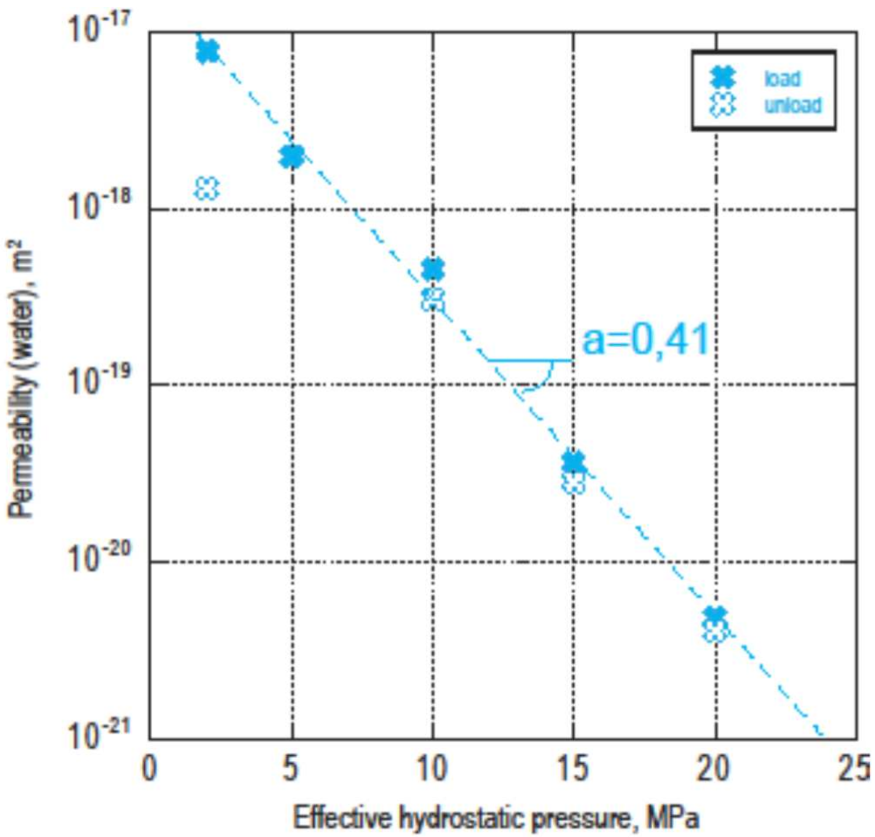
Brace *et al. (1968)*

Cracked glass permeability under confining pressure

argon



water



➡ $k = k_o e^{-aP}$ and $a^{-1} = P^* \sim 2.4$ MPa

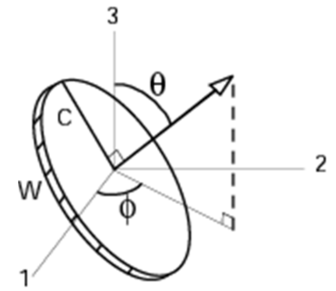
Comparison with low permeability rocks

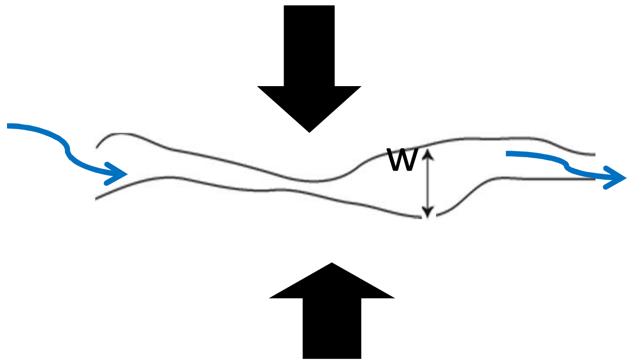
Reference	Rock type (low porosity rocks)	a, 10^{-2} MPa^{-1}	P^* = a^{-1}, MPa
YALE (1984)	tight sandstones	3.8 - 6.3	15.9 - 26.3
BRACE *et al.* (1968)	Westerly granite	3.3	30.6
BERNABE (1986)	Chelmsford granite	2.9	34.6
	Barre granite	2.3	42.7
FISHER and PATERSON (1992)	Carrara marble	4.7	21.3
HUENGES and WILL (1989)	Urach gneiss	4.9	20.4
MORROW *et al.* (1994)	gneiss [Kola]	3.2	31.2
	basalt [Kola]	10.2	9.8
	amphibolite [KTB]	5.8 - 11	9.1 - 17.2
	SON68 glass	a = 0.4 MPa^{-1}	P^* = 2.4 MPa

$$k = k_o e^{-aP}$$

Permeability and crack closure

Penny-shape crack





$\xi = w/c$

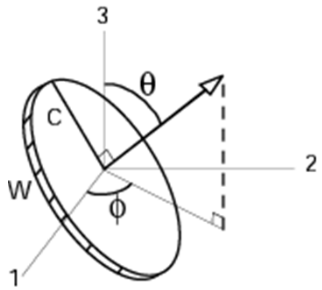
data → $k = k_o e^{-aP}$

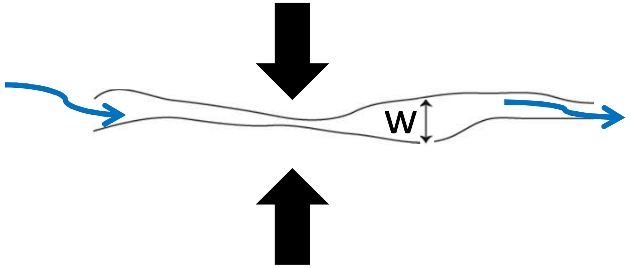
Crack elastic closure → $w \sim w_o (1 - \frac{P}{E\xi})$

Cubic law → $k \sim w^3$

P* value in cracked rocks and glass: $k = k_0 \, e^{-P/P^*}$

Penny-shape crack





$\xi = w/c$

$$k = k_o e^{-aP}$$

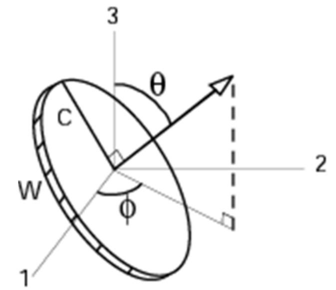
$$w \sim w_o \left(1 - \frac{P}{E\xi}\right)$$

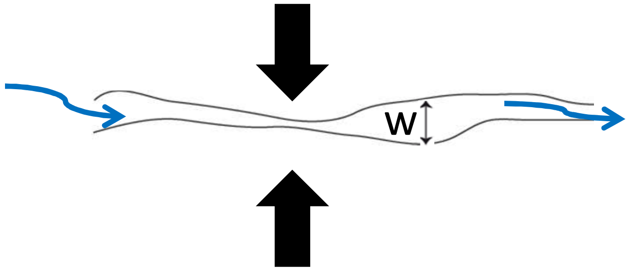
$$k_o e^{-aP} \propto w_o^3 \left(1 - \frac{P}{E\xi}\right)^3$$

This implies : $a = \dfrac{3}{E\,\xi}$ or : $P^* = E\xi / 3$

P* value in glass : $k = k_0 \, e^{-P/P^*}$

Penny-shape crack





$\xi = w/c$

$P^* = E\xi / 3$

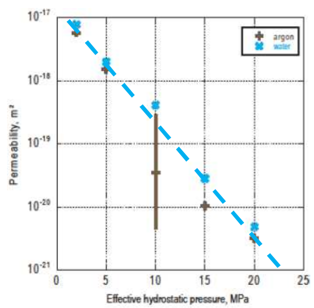
With : E = 80 GPa and $\xi = 10^{-4}$ → P* = 2.6 MPa

(Measured value: P = 2,4 MPa)*

In glass, no microstructure (but a nanostructure) → Very sharp crack tip

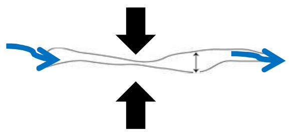
Conclusions: permeability of cracked rocks and glass

➡ Experimental data on cracked rocks and glass permeability with P



- **Permeability decreases follows** an **exponential law in cracked rocks and glass**

- **$k = k_0 e^{-P/P^*}$, where $P^* = E\xi / 3$**



- **Very sharp crack tips in glass : $P^* = 2 – 3$ MPa, aspect ratio** $\xi \sim 10^{-4}$

- **In rocks, $P^* = 10 – 40$ MPa**

  aspect ratio > 10^{-3}

➡ Further work in progress (see C. Mallet poster)