ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

9th Euroconference
Trondheim, Norway

Seismic wave attenuation at low frequencies: measurements and mechanisms

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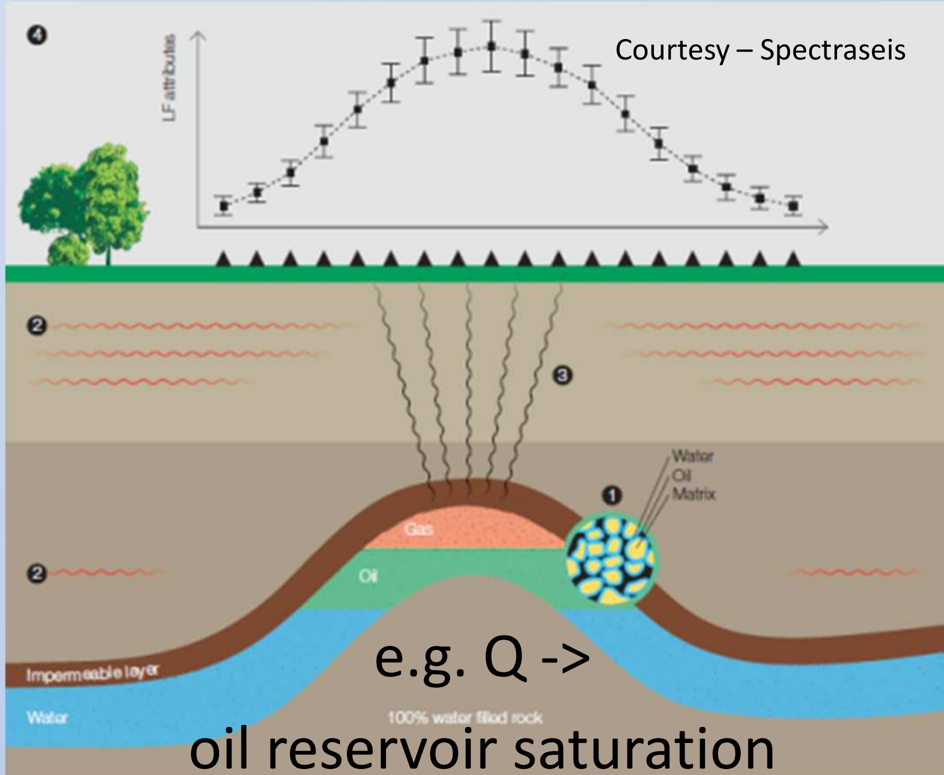
Why

- The study of fluid saturation of crustal rocks can be conducted with seismic wave attenuation at low frequency (Goloshubin et al., 2006).
- **Oil reservoirs** seem to exhibit **high-attenuation** (**low** Quality factor, **Q**) at low frequencies (Chapman et al. 2006).



e.g. Q ->
oil reservoir saturation

Introduction | Methods – BBAV | Q measurements | Q mechanisms | Conclusions

Theory

- **Attenuation** of seismic waves describes the **loss of energy** of the “elastic” perturbation.

- **Patchy Saturation** (White, 1975) and **Squirt Flow** (Mavko and Jizba, 1991) quantify the loss of energy due to fluid flow ($\Delta P \rightarrow \Delta V$) in porous media.

- Study of **Pore Pressure** is a key to get valuable **information** about these mechanisms.

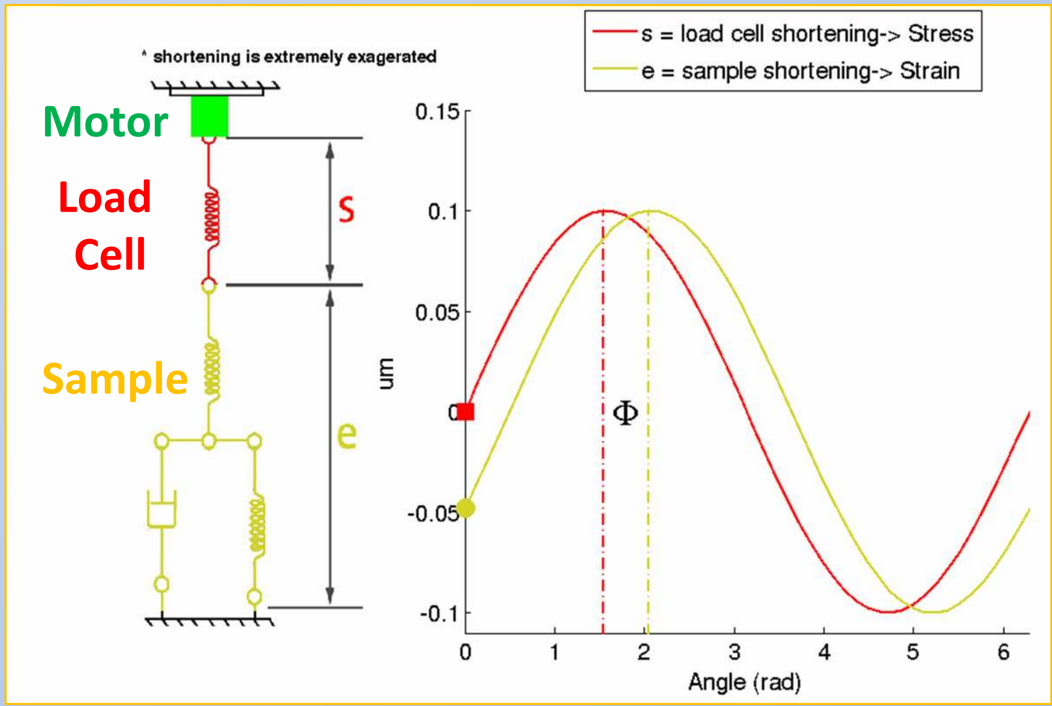
Method

Sub-resonance experiments
(e.g. Peselnik and Liu, 1987).

$$Q^{-1} = \tan(\Phi)$$

- Application of a "low" frequency (e.g. 0.1 - 100 Hz) sinusoidal stress.

- Measurements of the sinusoidal and "delayed" (Φ) shortening across the sample.

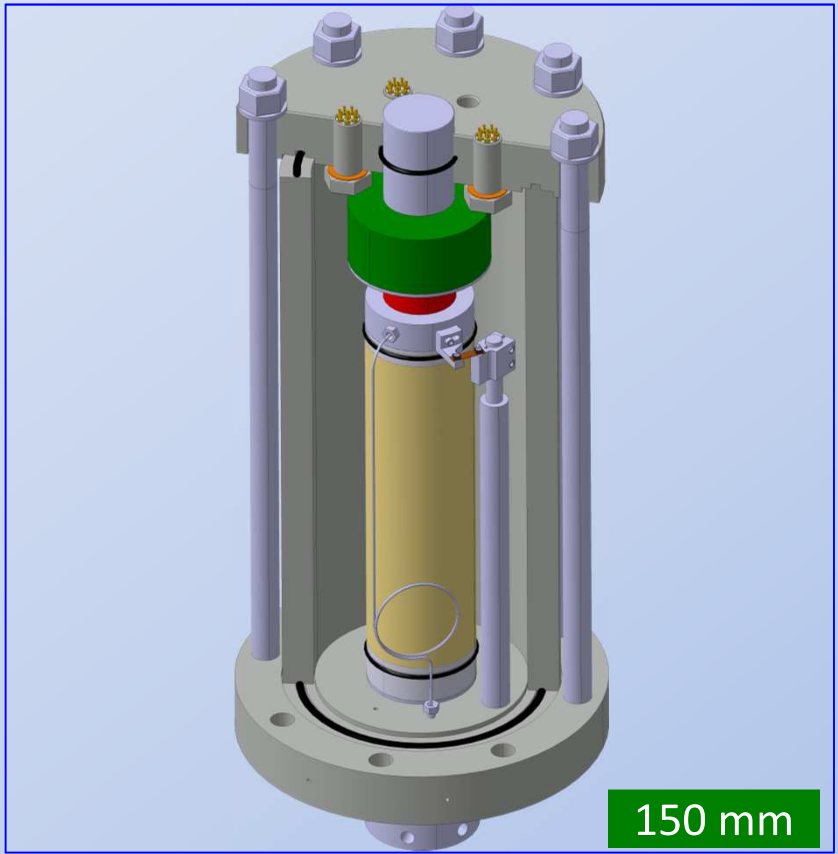


At ETH Zurich

2 machines for measuring Q

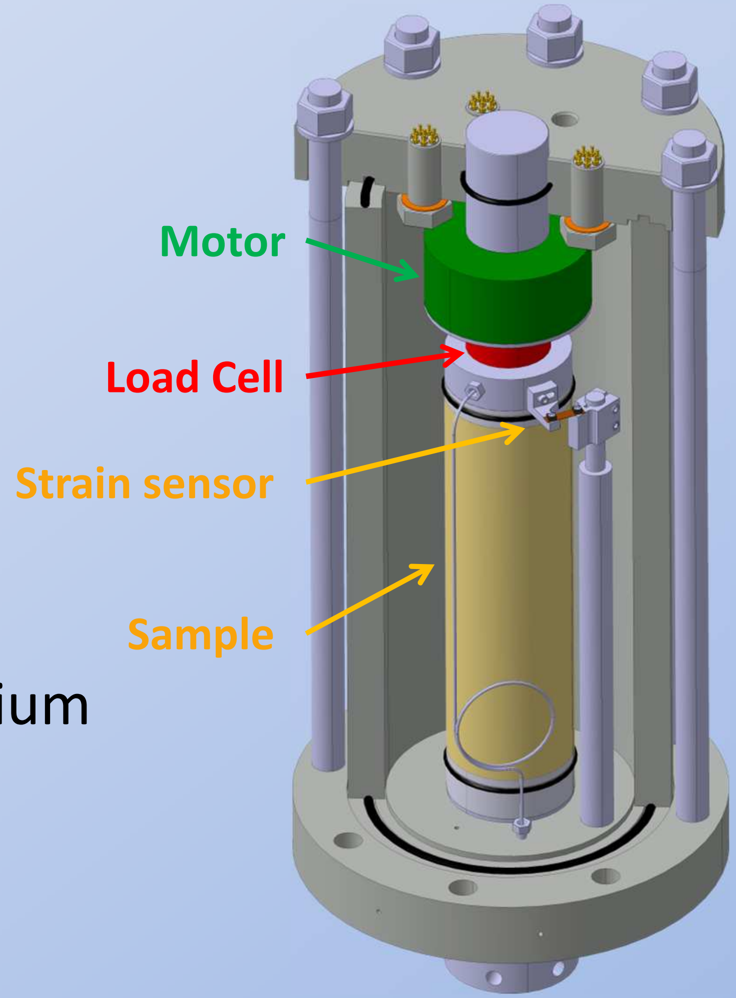
Broad Band Attenuation Vessel (BBAV)
Will be presented now

SWAM – Today poster session 3 (10:50-12:00)



BBAV

- **76 x 250 mm** cylindrical sample
- Measure of **local pore pressure**
- **Bulk** values of force and **strain** (10^{-6})
- **25 MPa** confining pressure in oil medium
- Full **pore fluids** circuit
- Fully automatic **400 points/day** in frequency range (0.1-100Hz)



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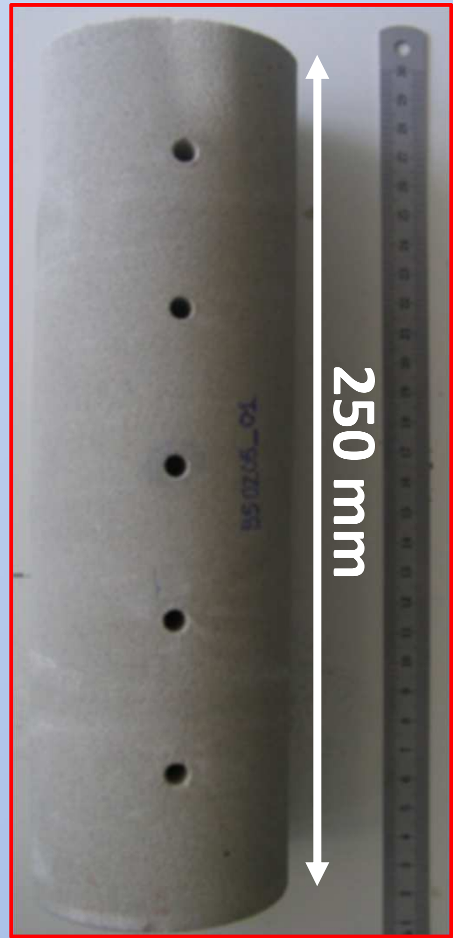
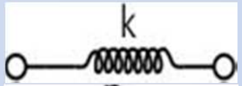
BBAV

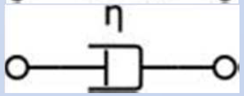
Big sample (250 mm long, 76 mm diameter) –> 5 pore pressure sensors

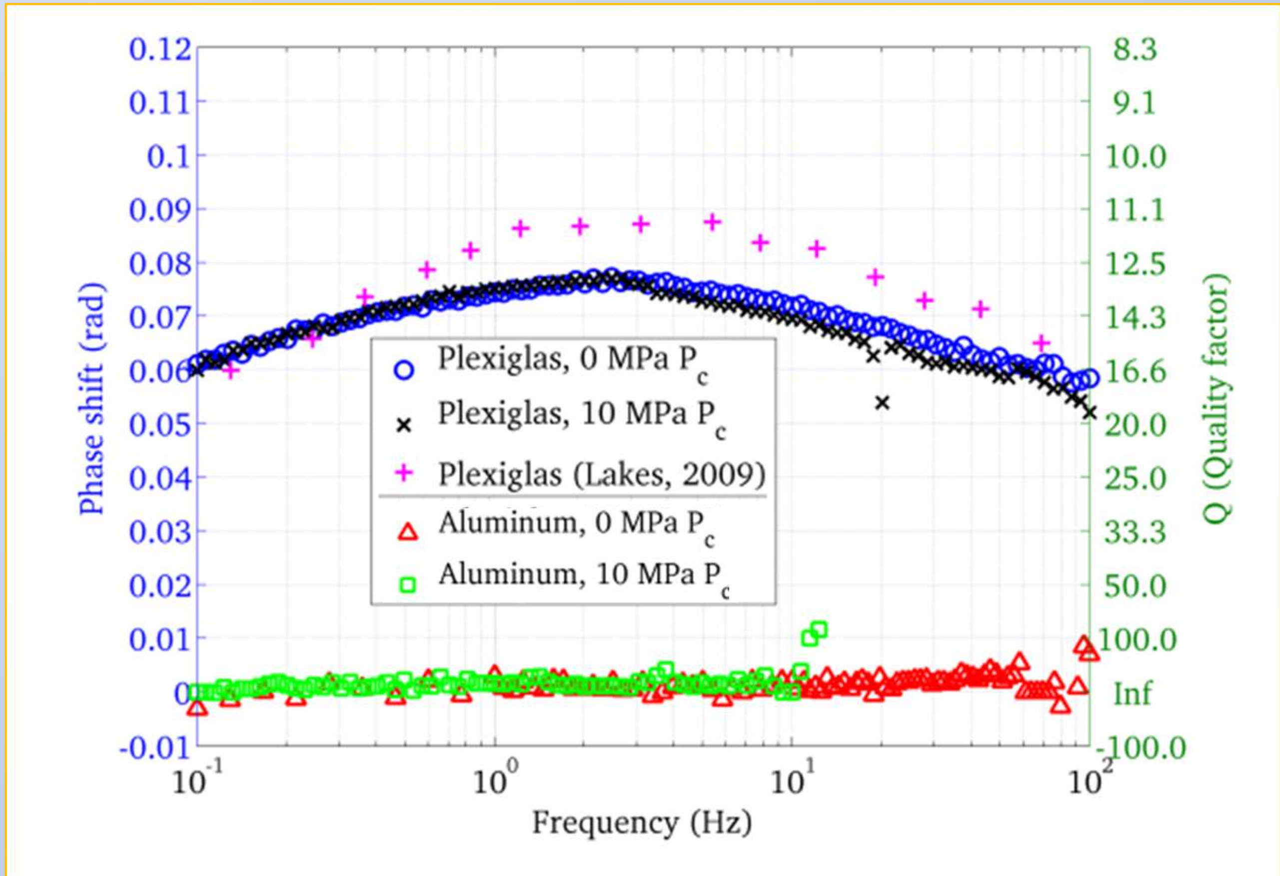


Calibration

Calibration obtained testing materials with “**known elasticity**”

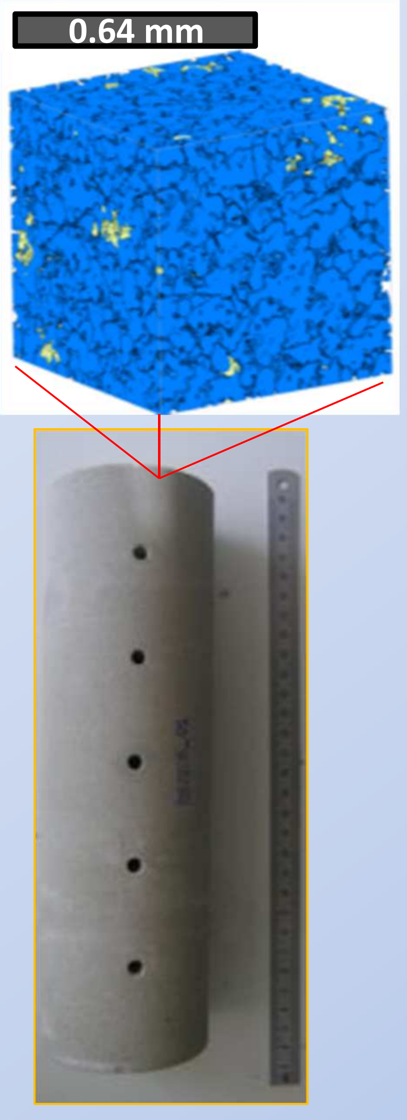
- Aluminum, Q -> Inf “  “ (Nowik and Berry, 1972)

- PMMA (Plexiglas), Q~12 “  “ (Lakes, 2009)



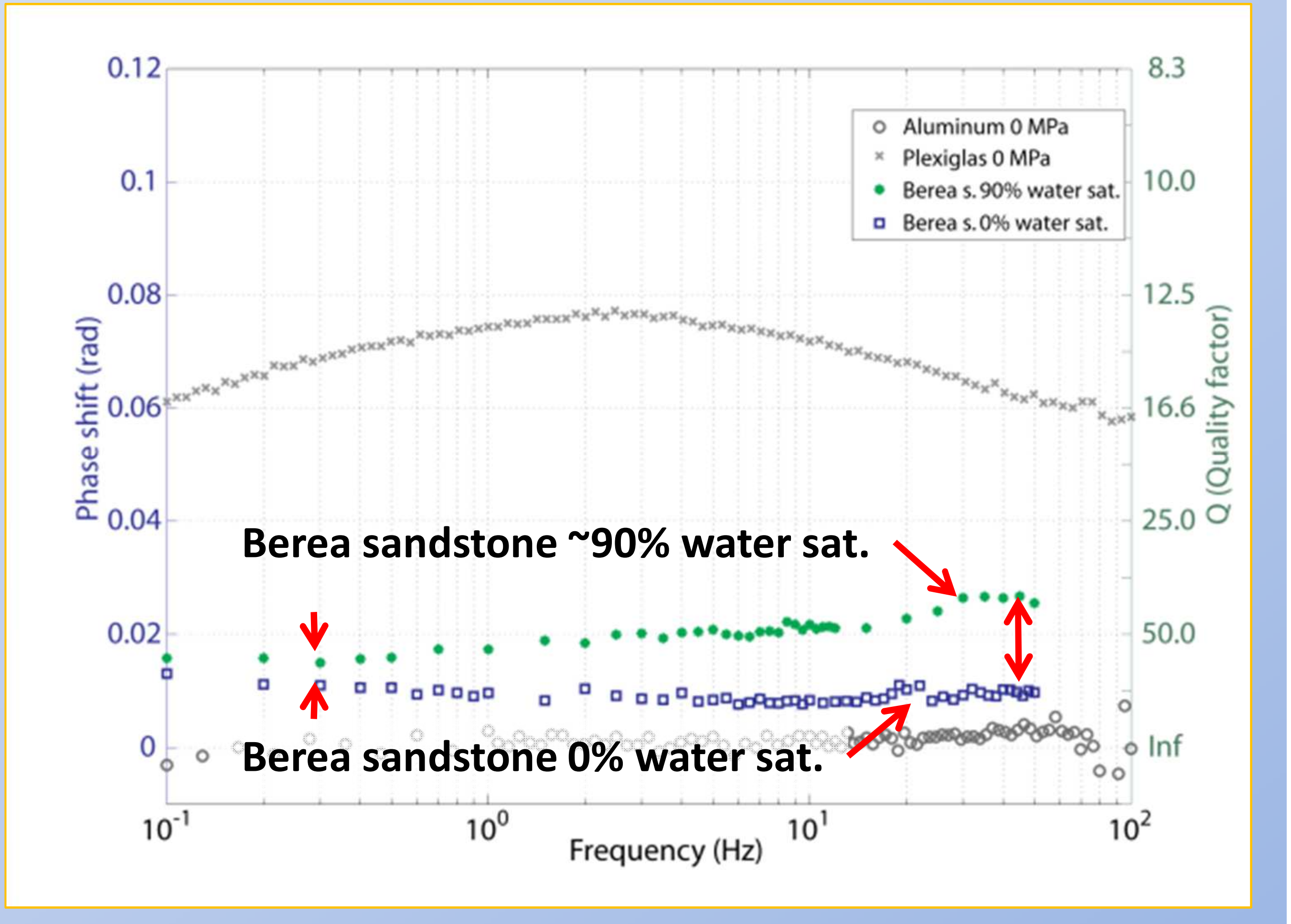
Rock data

Madonna et al. JGI sub.



Berea sandstone 200-500 mD, 20 % porosity

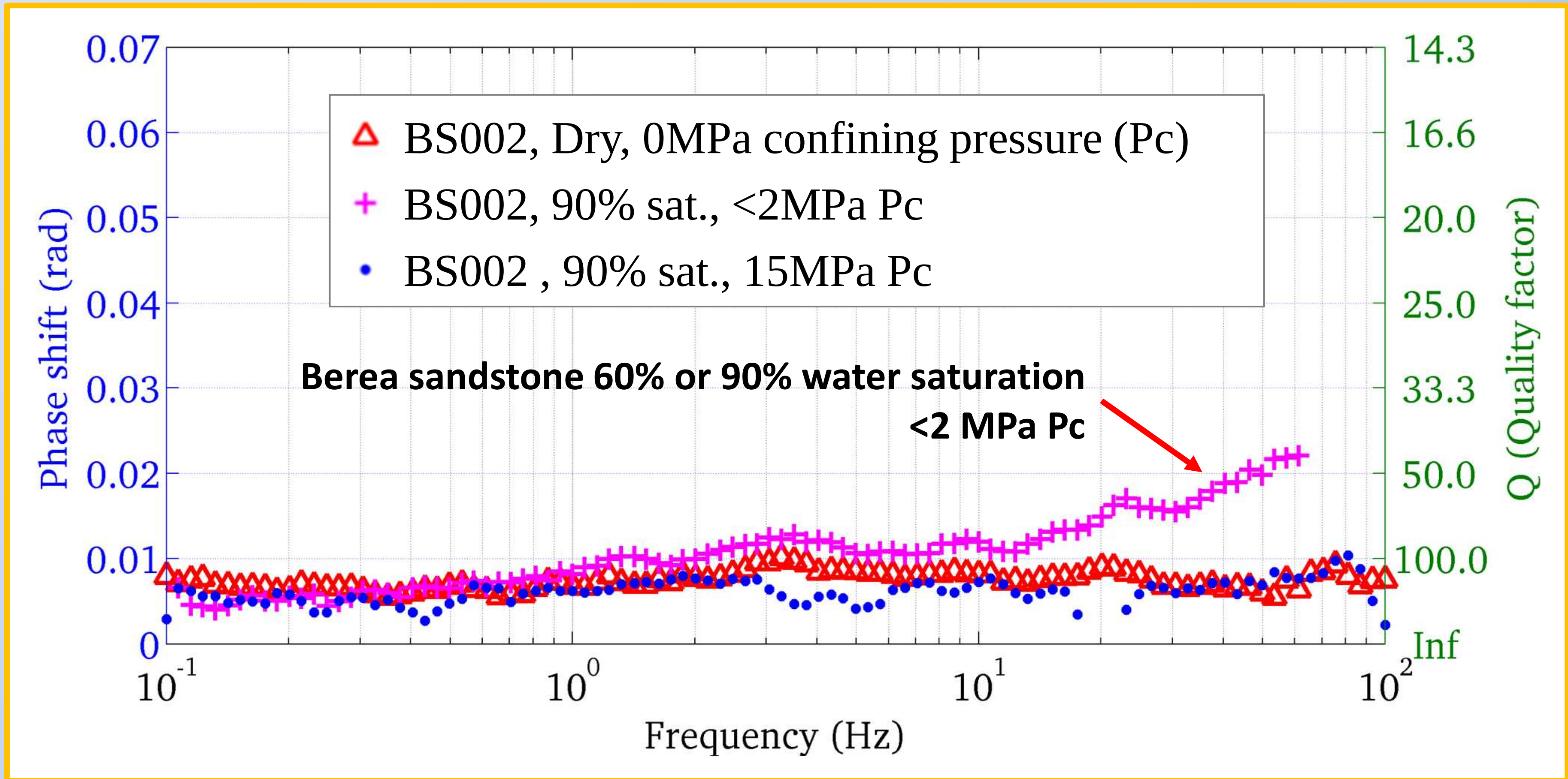
Water saturated at **0 and 90%, 0 MPa pore pressure**



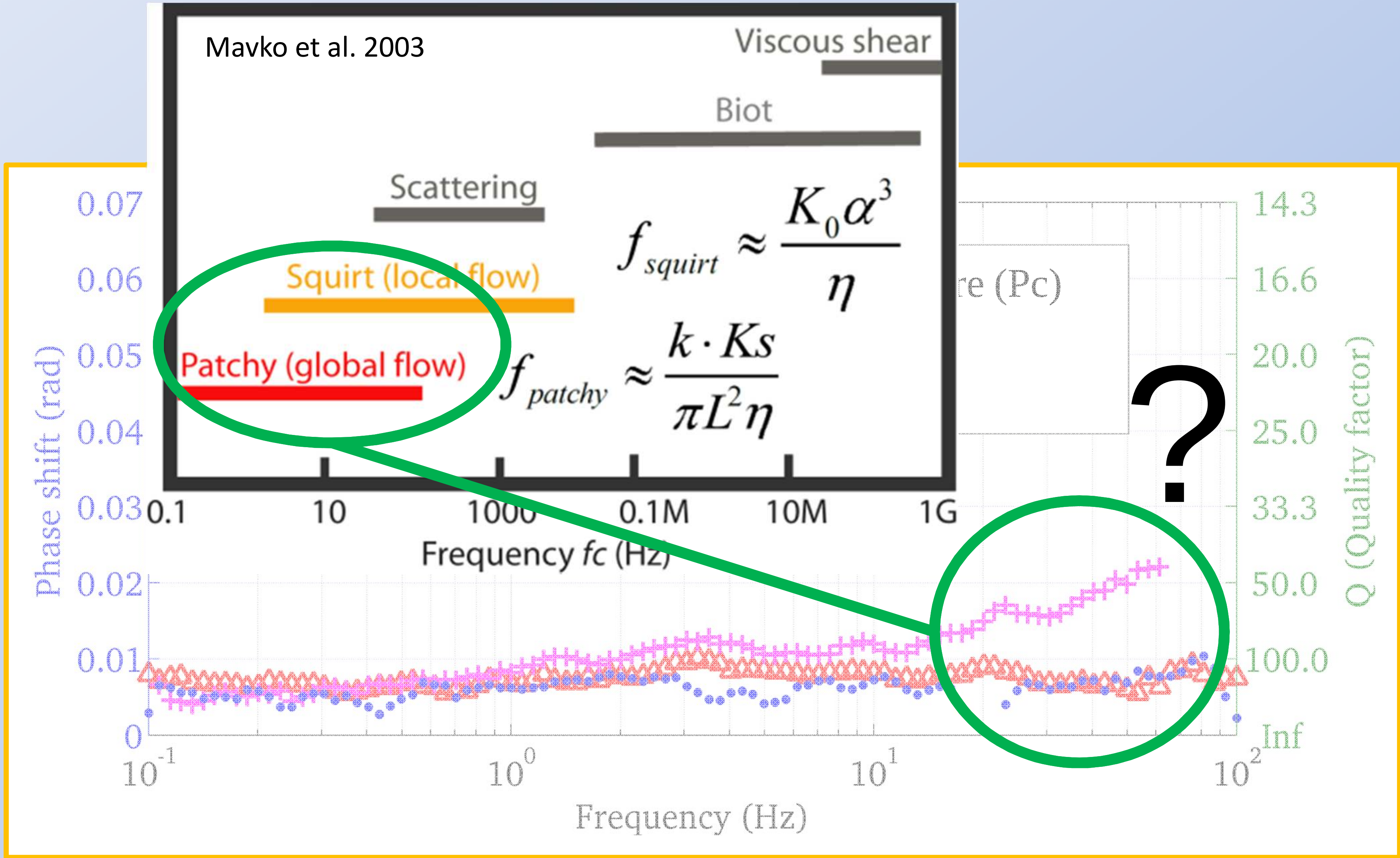
Rock data

Berea sandstone: 500-1000 mD, 20 % porosity

Water content 0 - 90%, **confining pressure** 0-15 Mpa, **0 MPa pore pressure**



Understanding



Understanding

Squirt flow (Mavko and Jizba 1998) exchange of fluids between cracks and pores

7 Hz < f_{squirt} < 7000 Hz

typical frequency of squirt (Hz)

$$f_{squirt} \approx \frac{K_0 \alpha^3}{\eta}$$

bulk module of Berea sandstone (7 GPa) (Hart and Wang 1995)

crack's aspect ratio (10^{-3}-10^{-4}) (Mavko et al. 2003)

viscosity of water (10^{-3}Pa s)

$1/C_{pc}$ 5 MPa

$1/C_{pc}$ = cracks closure pressure (Jaeger et al. 2007)

$$c_{pc} = \frac{2}{E_m}\left(\alpha + \frac{1}{\alpha}\right)$$

Berea sandstone:
$\alpha=10^{-4}$
E_m(matrix Young module): 97 GPa (Zimermann 1991)

cracks are closed at 15 MPa P_c

Preliminary rock data

Berea sandstone

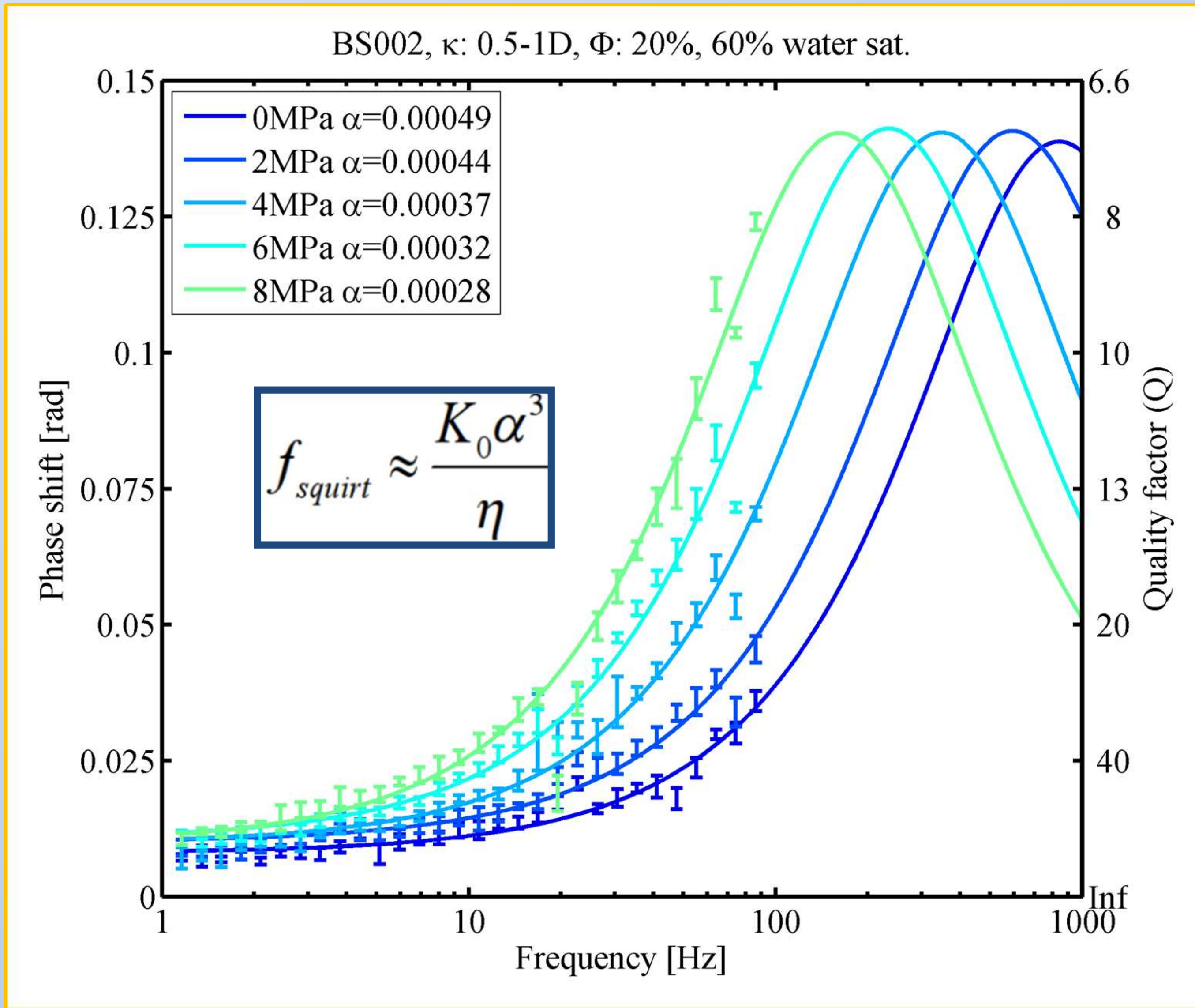
500-1000 mD
20 % porosity

60% Water content

Pc 0 - 15 MPa

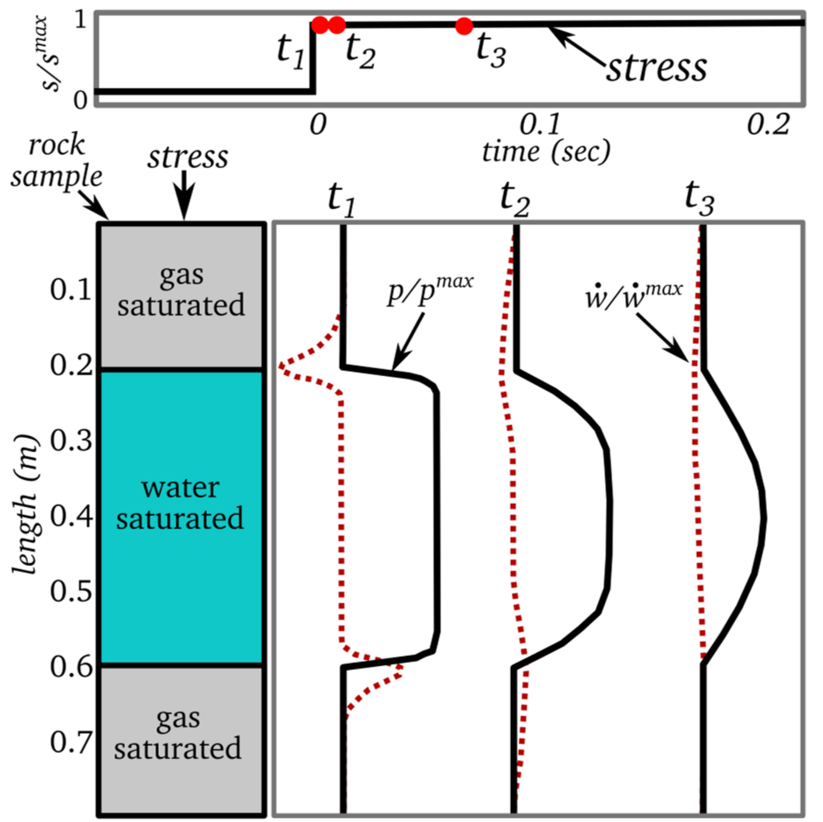
We need more calibrations and rock experiments

First approximation
K_0 constant



Uncovering of mechanisms

- The dimensions of the sample allow us to **insert in small holes some pressure sensors**
- **Verify patchy and/or squirt** flow theories

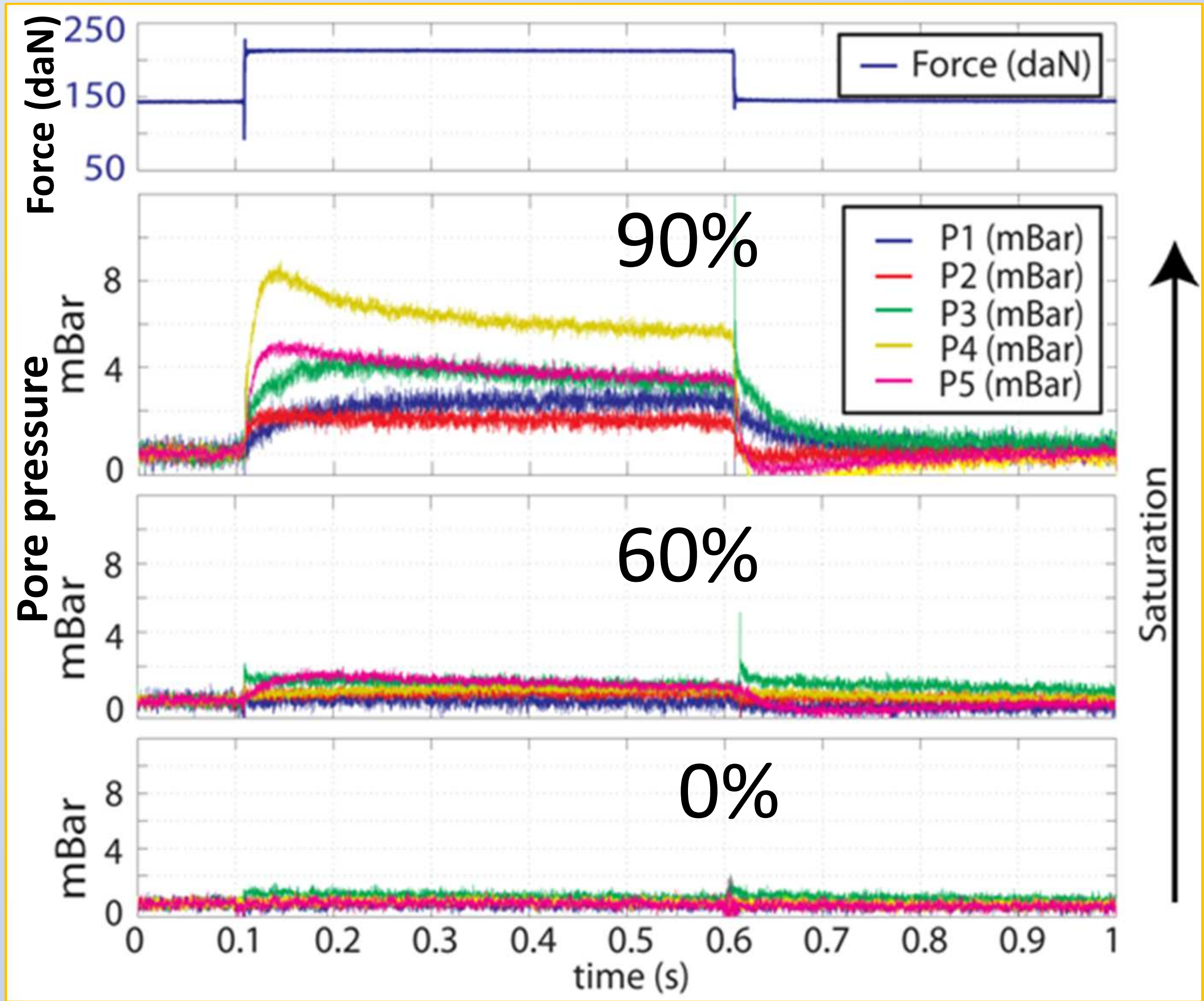


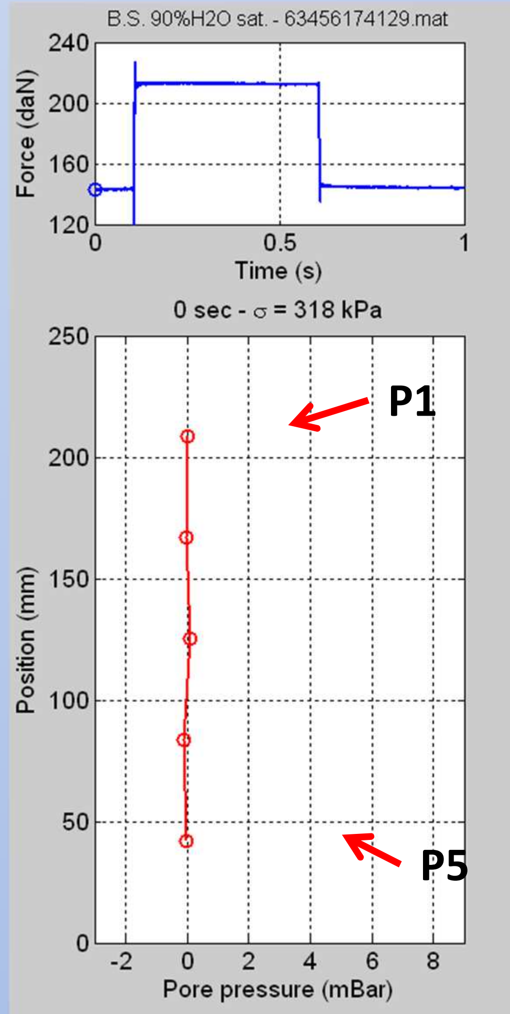
Quintal et al. 2011

Pressure sensor

Uncovering of mechanisms

Pore pressure evolution vs stress field change





Conclusions

- The B.B.A.V. has been designed, built and successfully tested

Q measurements from rock seem to indicate attenuation **driven by saturation**

Pore pressure measures suggest transfer of energy from elastic perturbation to fluid within the pores

- **Outlook:** measure Q values for different types of rocks at different **Confining Pressure and Saturation**

Acknowledgments

Luigi Burlini, mind and heart of this project, Jean-Pierre Burg, Reto Seifert and Robert Hofmann for the help. This research is founded by: KTI, Spectraseis, Low Frequency Seismic Partnership (LFSP)