Poroelastic relaxation in thermally cracked and fluid-saturated glass

Abdulwaheed Ògúnsàmì[1] , Jan Borgomano[2] , Jérôme Fortin[2] , and Ian Jackson[1]

[1]Australian National University, Research School of Earth Sciences, Canberra, Australia (ian.jackson@anu.edu.au)

[2]Ecole Normale Supérieure/CNRS, UMR8538, PSL Research University, Paris, France, Laboratoire de Géologie

Ògúnsàmì, A., Borgomano, J. V. M., Fortin, J., & Jackson, I. (2020). Poroelastic relaxation in thermally cracked and fluid‐saturated glass. *Journal of Geophysical Research: Solid Earth*, 125, e2019JB018890. https://doi/10.1029/2019JB018890

Abstract

To test the theoretical model of modulus dispersion in fluid-saturated cracked media, we examined the mechanical properties of four thermally cracked glass specimens of simple microstructure using complementary forced-oscillation (0.004–100 Hz) & ultrasonic techniques (~1 MHz).

We test the hypothesis that broadband mechanical behaviours of such synthetic specimens under fluid-saturated conditions should reveal the distinct fluid flow regimes due to fluid flow within the crack network and the consequent moduli dispersion and associated attenuation peak. The results indicate that in such fluid-saturated crack-only medium, squirt flow will result only in the dispersion of the shear modulus. Our findings illustrate the effect of cracks on moduli dispersion, support the effective medium theory with low aspect ratios cracks and validate the predictions from theoretical models of moduli dispersion.

1 Synthetic specimens: Thermally cracked (soda-lime-silica) glass rod with crack porosity only ($\phi < 1\%$)

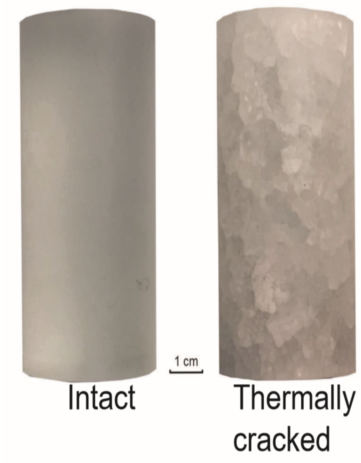
2 Permeability test: *In situ* prior permeability measurements guarantee full-saturation conditions for mechanical testing

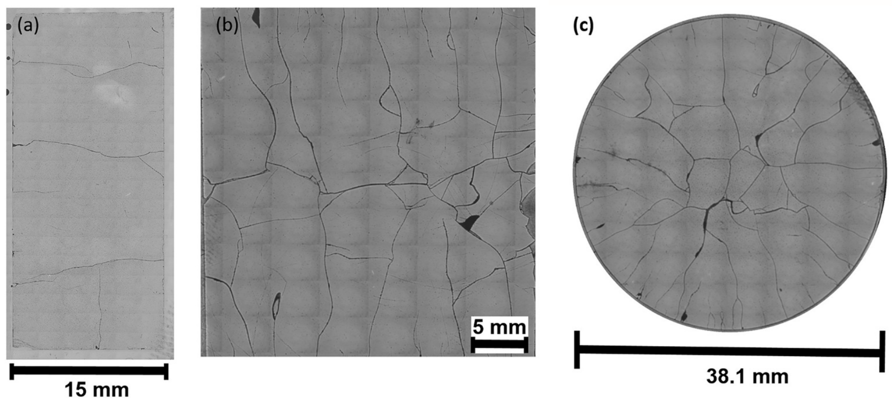
3 Drainage flow: Oscillation of confining pressure shows **bulk modulus dispersion and dissipation** localised near 2 mHz, only @ P_d = 2.5 MPa

4 Squirt flow: Extensional and torsional oscillation tests reveal **dispersion & dissipation** in shear near 0.3 Hz for P_d < 10 MPa

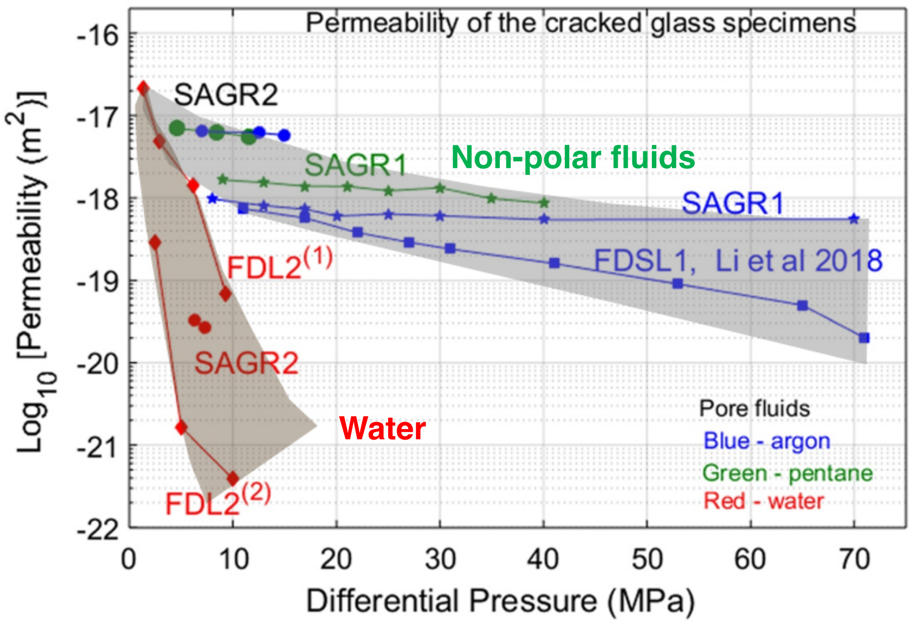
1 Synthetic Specimens

- Soda-lime-silica glass rods
- Heat treatment at 700°C and quenched in H_2O to induce cracks
- <1% crack porosity - of consistently low aspect ratio, mainly < 2 x 10^{-4}





2 Permeability



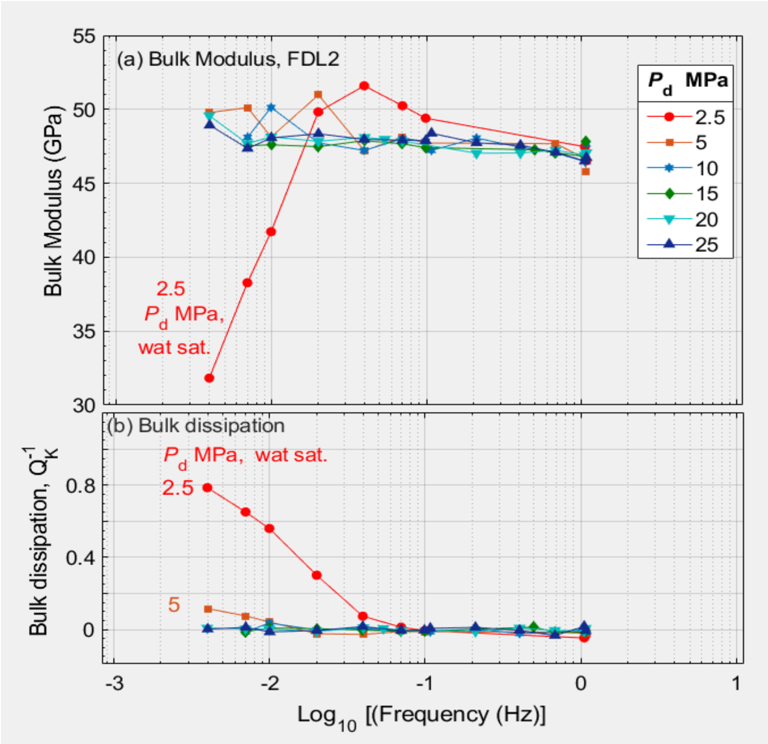
- Permeability tested with different pore fluids - argon, water and pentane.
- Permeability strongly pressure-dependent for P_d< 10 MPa
- Systematically lower permeability with water reflecting chemical interaction between polar fluid and siliceous crack surfaces

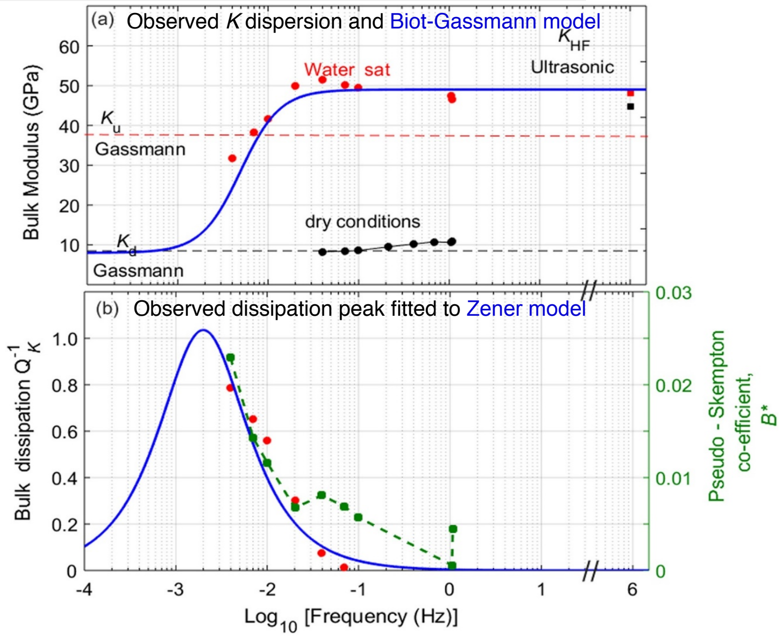
Confining pressure oscillation test

Bulk modulus dispersion and dissipation for water–saturated conditions

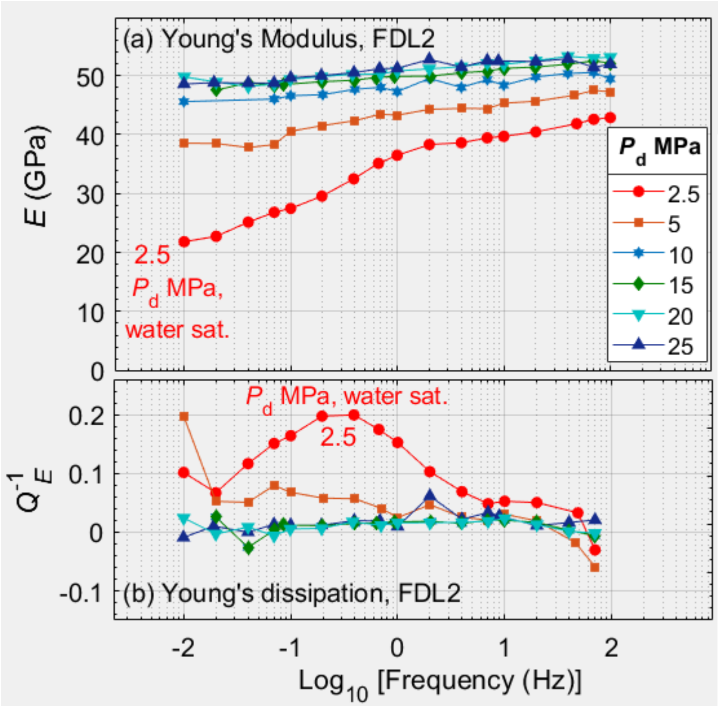
3 Drainage flow

- Strong bulk modulus dispersion & dissipation only @ lowest P_d = 2.5 MPa
- Associated variation of pseudo-Skempton coefficient $B^* = \delta P_f / \delta P_c$ confirms fluid flow between specimen and external reservoir
- K dispersion and dissipation centred near 2 mHz, well described by Zener model – reflecting drainage flow

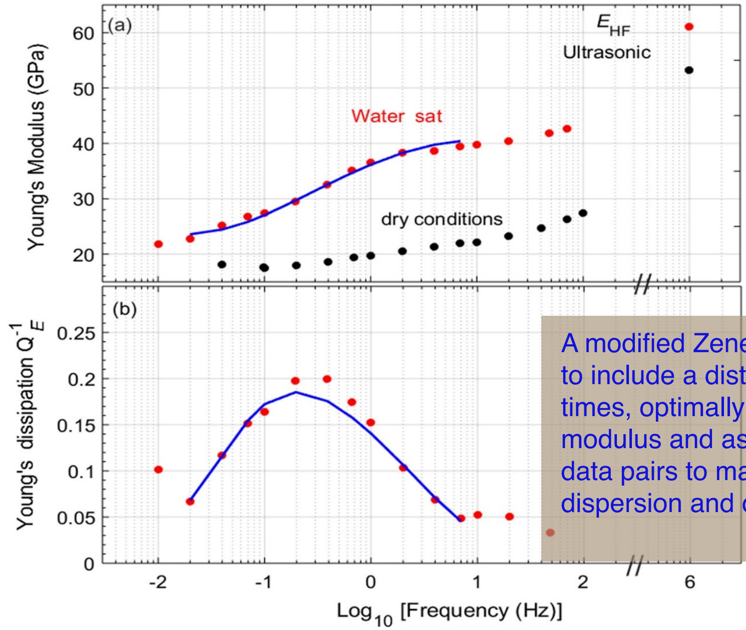




- ❑ E dispersion and dissipation at P_d = 2.5 MPa peak near 0.3 Hz



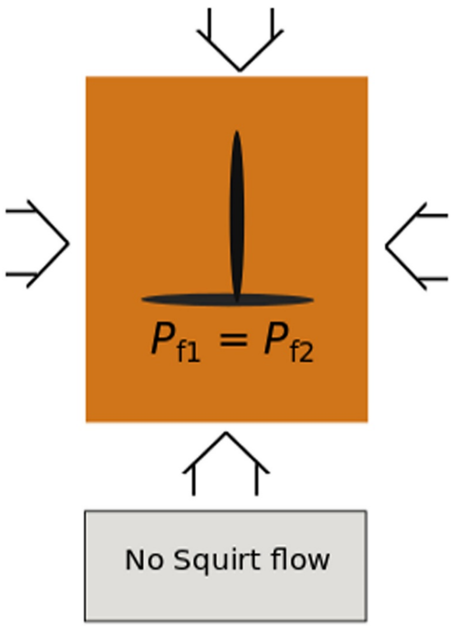
- ❑ Markedly decreasing E, ν and Young's dissipation with increasing P_d indicate pressure -induced crack closure – highlighting role of the low aspect ratio cracks.
- ❑ E dispersion and dissipation at P_d = 2.5 MPa adequately modelled with a continuous distribution of relaxation times over two decades – reflecting the influence of squirt flow on the shear modulus.



A modified Zener model extended to include a distribution of relaxation times, optimally fitted to Young's modulus and associated dissipation data pairs to match the observed dispersion and dissipation peak.

Squirt flow and Dispersion in crack-only porous medium

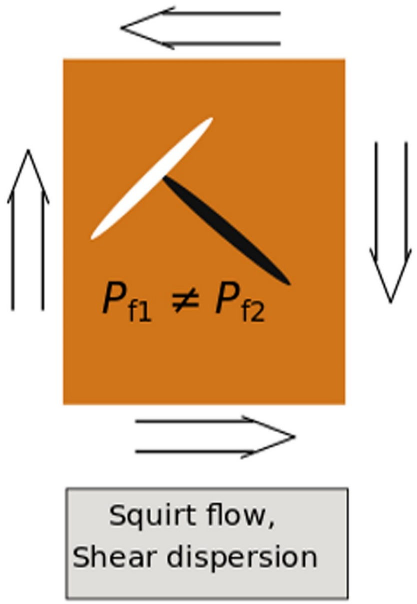
Hydrostatic pressure



Uniform pore pressure within randomly oriented cracks of given aspect ratio

- ❑ No driving force for squirt flow.
- ❑ So *K* remains unchanged across saturated isobaric (undrained) regime to the saturated isolated regime.

Pure Shear stress



Pore pressure varies with crack orientation relative to the stress field

- ❑ Squirt flow driven by pore pressure gradients between adjacent cracks.
- ❑ *G* dispersion occurs between the saturated isobaric and saturated isolated regimes.

Effective elastic response for a medium containing only cracks, of random orientation with a given aspect ratio α, under hydrostatic compression (left) and shear stress (right). P_{f1} and P_{f2} are the pore fluid pressures in representative cracks with diverse orientation relative to the applied stress

Australian National University

Summary and outlook

Permeability and seismic properties have been measured with complementary techniques on a suite of thermally cracked glass specimens

The fluid saturated specimens show frequency dependent properties – first evidence of both drainage and squirt flow transition in a synthetic cracked medium

Our findings present new insight into the seismic properties of a fluid-saturated synthetic medium which contains only cracks with a narrow distribution of aspect ratios

Future work involves the testing the broadband seismic properties of fluid-saturated sintered glass beads specimens – cracked and intact.