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Bubbles cause seismic wave attenuation: Laboratory measurements and numerical simulations

Nicola Tisato (1,3), Beatriz Quintal (2), Samuel Chapman (2), Yury Podladchikov (2), Giovanni Grasselli (1), and Jean-Pierre Burg (3)

(1) University of Toronto, Department of Civil Engineering, Toronto, Canada (nicola.tisato@utoronto.ca), (2) University of Lausanne, Institute of Earth Sciences (ISTE), Geopolis building, 1015 Lausanne, Lausanne, Switzerland (beatriz.quintal@unil.ch), (3) ETH Zürich, Geological Institute, Sonneggstrasse 5, 8092 Zürich, Switzerland (jean-pierre.burg@erdw.ethz.ch)

Seismic wave attenuation ($1/Q$) is a key to uncover the saturation and, in general, to improve the monitoring and surveying of subsurface domains. Nevertheless, how fluids that saturate rocks absorb elastic energy (i.e. cause $1/Q$) is still poorly understood, studied and incorporated in geophysical methods.
One of the invoked mechanisms, wave induced fluid flow (WIFF), is reputed to cause significant attenuation. This mechanism is governed by the flow of viscous fluids into a porous rock, and causes attenuation as a function of the fluid diffusivity [m^2/s] and the pressure gradient [Pa/m], which is generated by the propagation of the elastic wave. However, some published, and newly acquired laboratory data-sets reporting $1/Q$ in almost fully saturated sandstones are difficult to explain with WIFF theories as they are frequency-dependent and have maximum of attenuation at frequencies <20 Hz.
We demonstrate that micrometric gas-bubbles, dispersed in the liquid which saturates the pores of the studied specimen, cause the unexplained “low” frequency-dependent attenuation. We utilize a theoretical model calculating the exsolution-dissolution of spherical gas-bubbles in a liquid to fit the laboratory data-set. In saturated pores, the strain caused by the propagating seismic wave preferentially deforms the gas-bubbles. This deformation is the sum of the elastic expansion of the gas and the dynamic exsolution-dissolution of the gas in the liquid. The dynamic exsolution-dissolution mechanism is governed by the exchange of gas between the bubble and the liquid, which is controlled by the gas diffusivity [m^2/s] and, therefore, it is time dependent (i.e. frequency-dependent).
In fact, this attenuation mechanism, which hitherto was only postulated, absorbs energy because the transient fluid pressure, generated by the propagating seismic wave, modifies the thermodynamic equilibrium between the gas in the bubble and the surrounding liquid. Finally, we present a numerical experiment simulating the propagation of a seismic wave in a subsurface domain saturated with a gas-bubble bearing fluid, demonstrating that this mechanism can measurably modify the propagation of seismic waves in the subsurface.
The vertical migration of subterranean gas-bubbles can cause damageable events, such as the release of greenhouse gases from thawing permafrost or sub-permafrost formations or volcanic eruptions. Therefore, the present contribution is of major impact for geophysics, volcanology and climate warming mitigation as it reports a new attenuation mechanism that, if incorporated in seismic inversion workflows, will improve the monitoring and surveying of subsurface domains which are saturated with gas-bubble bearing fluids.