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Characterization of seismic properties across scales: from the laboratory- to the field scale

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When exploring geothermal systems, the main interest is on factors controlling the efficiency of the heat exchanger. This includes the energy state of the pore fluids and the presence of permeable structures building part of the fluid transport system. Seismic methods are amongst the most common exploration techniques to image the deep subsurface in order to evaluate such a geothermal heat exchanger. They make use of the fact that a seismic wave caries information on the properties of the rocks in the subsurface through which it passes. This enables the derivation of the stiffness and the density of the host rock from the seismic velocities. Moreover, it is well-known that the seismic waveforms are modulated while propagating trough the subsurface by visco-elastic effects due to wave induced fluid flow, hence, delivering information about the fluids in the rock's pore space.

To constrain the interpretation of seismic data, that is, to link seismic properties with the fluid state and host rock permeability, it is common practice to measure the rock properties of small rock specimens in the laboratory under in-situ conditions. However, in magmatic geothermal systems or in systems situated in the crystalline basement, the host rock is often highly impermeable and fluid transport predominately takes place in fracture networks, consisting of fractures larger than the rock samples investigated in the laboratory. Therefore, laboratory experiments only provide the properties of relatively intact rock and an up-scaling procedure is required to characterize the seismic properties of large rock volumes containing fractures and fracture networks and to study the effects of fluids in such fractured rock.

We present a technique to parameterize fractured rock volumes as typically encountered in Icelandic magmatic geothermal systems, by combining laboratory experiments with effective medium calculations. The resulting models can be used to calculate the frequency-dependent bulk modulus $K(\omega)$ and shear modulus $G(\omega)$, from which the P- and S-wave velocities $V_P(\omega)$ and $V_S(\omega)$ and the quality factors $Q_P(\omega)$ and $Q_S(\omega)$ of fluid saturated fractured rock volumes can be estimated. These volumes are much larger and contain more complex structures than the rock samples investigated in the laboratory. Thus, the derived quantities describe the elastic and anelastic (energy loss due to wave induced fluid flow) short-term deformation induced by seismic waves at scales that are relevant for field-scale seismic exploration projects.