Coda wave interferometry during the heating of deep geothermal reservoir rocks

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ABSTRACT

Coda Wave Interferometry (CWI) is a high-resolution technique that aims at tracking small perturbations in a diffusive medium from the correlation of seismic waveforms (Snieder, 2006). Thanks to the development of seismic noise correlation methods and of the plentiful records of ambient seismic noise in time, CWI has been used in recent years to monitor the fine-scale evolution of fault zones and more recently of deep reservoirs (e.g. Sens-Schönfelder and Wegler (2011), Lehujeur et al. (2014)).

However, to provide a quantitative interpretation of the reservoir monitoring, direct modeling of the physical effects like the influence of the temperature on seismic wave scattering, is required to invert temperature effects from measurements of velocity changes. We quantify here the impact of thermo-elastic deformation on seismic wave diffusion following both a numerical and an experimental approach. The latter is based on experimental results from Griffiths et al. (2018) obtained on a deep geothermal representative granitic rock (i.e. Westerly Granite) for which CWI monitoring is performed during the repeated heating and cooling of the sample. We developed a numerical model that replicates the experiments. The numerical modelling initially proposed by Azzola et al. (2018) combines the thermo-elastic deformation obtained from a finite element approach (Code_Aster) to the wave propagation simulation obtained from a spectral element approach (SPECFEM2D). A stretching technique is applied as in the laboratory to quantify waveform changes. First, the simulations only account for the thermo-elastic dilatation of the bulk and complementary simulations include changes of Young and bulk moduli with temperature. The comparison between the laboratory and simulated results intends to better understand the physical origins of the CWI measurements.

Our study shows first that multiple reflections on the boundaries of the numerical sample reproduce the wave scattering happening in the granite sample that includes a set of mineral inclusions and of micro-cracks. The comparison is based on the wave diffusion model describing similarly both experimental and numerical samples. The samples share also a similar thermo-elastic behavior in the simulation and in the laboratory experiments but only after the second heating and cooling cycle. In addition, we show that the CWI measurements reveal reversible time shifts correlated to the thermo-elastic deformation of the sample in both approaches. Meanwhile, the influence of thermo-elastic deformation differs from the numerical proxy to the real granitic sample. We introduce temperature dependence of elastic moduli in the model in order to discuss the role of irreversible deformation (e.g. micro-cracking) in the difference in behavior highlighted. These results suggest that there are open perspectives to monitor thermal strain in geothermal reservoirs using CWI.

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