Geophysical Research Abstracts
Vol. 20, EGU2018-12287, 2018
EGU General Assembly 2018

Modeling of wave diffusion from thermal cracking

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Coda Wave Interferometry (CWI), is a high-resolution technique that aims at tracking small changes in a diffusive propagation medium, from the comparison of waveforms. It has been conducted on Westerly Granite while heating and cooling cored samples to 450 °C in multiple cycles. Such an experiment aims at monitoring non-permanent and permanent effects, i.e. thermos-elastic effects and mainly thermal micro-cracking. If large and mostly permanent changes in the waveforms were measured during the first cycle, interpreted as an apparent reduction in velocity with temperature, the following cycles show further but reduced velocity reduction. For a better understanding of these behaviors and to discuss the physical origins of these CWI measurements, we developed a 2D numerical analysis replicating the experiment. The sample is a uniformly meshed 2D-plate whose mechanical and thermal characteristics fit those of the Westerly Granite used in the laboratory. The principle of the numerical modeling is to combine two codes. The thermos-elastic deformation of the mesh is obtained from a finite element approach (Code_Aster), while temperature is progressively increased by 10°C steps from 20°C to 450°C. The wave propagation is simulated within the mesh from a spectral element approach (SPECFEM2D) at each temperature step.
Interestingly, in such a numerical approach, parameters like wave velocity are set constant during the whole thermal load independently of any thermal cracking. The focus is on the effect of the thermo-elastic material deformation independently of intrinsic wave velocity variations. Such invariance to wave speed variations is a real advantage with respect to laboratory experiments where both effects are generally very difficult to distinguish. In the numerical modelling, CWI is applied to the simulated seismograms to quantify waveform changes during the thermal loading. Both a stretching technique and a cross-correlation method show that time shifts of the CWI are correlated to the thermos-elastic deformation of the mesh.
In the laboratory, irreversible relative decrease in velocity of several percent are measured during the first cycle and near-reversible changes in the wave velocity are measured during subsequent and identical heating cycles. These relative changes, linked to the presence of new thermal microcracks, are not reproduced in our numerical analysis. However when thermos-elastic deformation dominates, experiments and simulations show similar linear behaviours of the CWI but with different magnitudes. To improve the similarity between the numerical and experimental observations, we show that introducing elliptic holes (rather than round holes) is relevant. These results suggest that scatters are rather elongated micro-crack cavities than round mineral grains.