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Simulation of seismic waves in the brittle-ductile transition (BDT) using a Burgers model

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The seismic characterization of the brittle-ductile transition (BDT) in the Earth's crust is of great importance for the study of high-enthalpy geothermal fields in the proximity of magmatic zones. It is well known that the BDT can be viewed as the transition between zones with viscoelastic and plastic behavior, i.e., the transition between the upper, cooler, brittle crustal zone, and the deeper ductile zone. Depending on stress and temperature conditions, the BDT behavior is basically determined by the viscosity of the crustal rocks, which acts as a key factor. In situ shear stress and temperature are related to shear viscosity and steady-state creep flow through the Arrhenius equation, and deviatory stress by octahedral stress criterion.

We present a numerical approach to simulate the propagation of P-S and SH seismic waves in a 2D model of the heterogeneous Earth's crust. The full-waveform simulation code is based on a Burgers mechanical model (Carcione, 2007), which enables us to describe both the seismic attenuation effects and the steady-state creep flow (Carcione and Poletto, 2013; Carcione et al. 2013). The differential equations of motion are calculated for the Burgers model, and recast in the velocity-stress formulation. Equations are solved in the time domain using memory variables. The approach uses a direct method based on the Runge-Kutta technique, and the Fourier pseudo-spectral methods, for time integration and for spatial derivation, respectively. In this simulation we assume isotropic models.

To test the code, the signals generated by the full-waveform simulation algorithm are compared with success to analytic solutions obtained with different shear viscosities. Moreover, synthetic results are calculated to simulate surface and VSP seismograms in a realistic rheological model with a dramatic temperature change, to study the observability of BDT by seismic reflection methods. The medium corresponds to a selected rheology of the Iceland scenario (Violay et al. 2012), with steep velocity gradient, and assuming deep basaltic rock with low content of glass. The analysis shows the importance of the assessment of the Arrhenius parameters for the characterization and definition of the rheological models in the simulation of wave propagation in geothermal areas.

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