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A Burgers-Brittle model for the seismic-aseismic, brittle-ductile transition within the Earth crust

Véronique Dansereau, Nikolai Shapiro, Michel Campillo, and Jérôme Weiss

Institut des Sciences de la Terre (CNRS UMR5275)

The rheological stratification of the subducting frontiers of plate tectonics is nowadays recognized. So is the spatial correlation between the transient Episodic Tremor and Slip (ETS) processes and the brittle-ductile transition that sits between the seismic zone at the surface and the aseismic zone at depth. However, the mechanical processes underlying ETS, their relation to a mixed brittle-ductile rheology and the feedbacks between highly localized and distributed deformations and between ETS and major earthquakes are still not well established. One of the main reason is the lack of direct models that can represent the deformation of subduction zones as a whole (the continental and oceanic plates, their interface and the upper mantle) and that can be compared to seismic and geodetic observations of ETS. In this context, we propose a new continuum, Finite Elements-based model that can serve as a tool to improve the current understanding of the seismic-aseismic, brittle-ductile transition within the Earth crust.

The framework is based on the visco-elastic Burgers rheology. Here, the Maxwell element accounts for the permanent (transient and steady state) deformations within the shearing zone and both plates and the Kelvin-Voigt element accounts for the visco-elastic adjustment of the upper mantle. A unique constitutive equation is applied to the entire system, but the mechanical behavior of each of its parts is differentiated by allowing the elastic modulus and effective viscosity associated with the Maxwell element to evolve in both space and time according to the level of fracturing at the sub-grid scale. This is represented by a scalar damage variable, which increases locally when the state of stress becomes overcritical with respect to a Mohr-Coulomb criterion and decreases logarithmically due to sealing at the sub-grid scale. The coupling is such that within undamaged zones, the relaxation of the stresses is stable and set by the bulk viscosity of the bedrock while within damaged zones, such as the shearing interface of the plates, the deformation is acomodated by a combination of seismic, brittle fracturing and aseismic, transient stress relaxation processes.

The idealized 2-dimensional simulations of the brittle-ductile transition in a subduction zone that will be presented shows that the model represents a damaged shearing zone between the continental and oceanic plates. This zone, which concentrates the deformation, is maintained in time and space through a competition between brittle fracturing events, stress redistribution and healing processes. In between large damage events, associated with major earthquakes, the

damage activity is correlated over a wide range of time scales.