The mechanics and physics of faults: from brittle earthquakes to slow seismic events

The knowledge of the shear resistance (friction) evolution along a pre-existing fault is of major importance, as it allows extracting information about the characteristics and features of seismic slip. In particular, the decrease of friction with increasing velocity or displacement (a process called frictional weakening) determines the possible nucleation of earthquakes. If the weakening rate is larger than a critical value, this leads to the triggering of a dynamic slip at the origin of earthquakes. In addition to nucleation, the evolution of the friction coefficient- and thus of the fault's shearing resistance- also determines the arrest of the fault slip and governs the form and budget of energy dissipation during seismic slip. The latter is essential as it determines the amount of energy produced at the fault and radiated on the surface through seismic waves and tremors. It is nowadays accepted, that only a small fraction of the seismic energy is radiated, with the majority of the energy budget being consumed in material processes inside the fault. Such processes are mainly thermal in origin, like for instance thermal pressurization or chemical transformations, forcing the fault's frictional response to admit thermal-chemical weakening upon slip.

These thermal-chemical mechanisms seem to characterize the frictional response of faults in both brittle and ductile environments. Indeed, the so-called Episodic Tremor and Slip (ETS) sequences recorded both in GPS and seismic data, are slow seismic events, rooted in the ductile domain at the interface of subduction zone and overriding plate, at a depth of around 20-30 km. These seismic tremors are signatures of deep fluid injection similar to the well-known volcanic tremors, with the fluid source being suggested to be related to the breakdown of the serpentinite group minerals such as antigorite or lizardite. This implies that in subduction zones mineral reactions also appear to be a key mechanism of the ETS sequence, offering a unifying mechanism (thermal-chemical effects in the shearing resistance of faults) that is present both in brittle and ductile environments. It is therefore becoming apparent that if faults in both environments abide to similar physics, appropriate constitutive laws that account for both brittle and ductile shearing resistance -as well as the effects of temperature and mineral reactions- are required to offer a unifying view of the response of faults.

In this talk such a model will be presented, showcasing that weak phase- and/or fluid- production reactions control a fault slip response depending on the in-situ confinement and temperature. Faults of the same material can slip in a fast seismic or slow episodic manner; depending on the depth and thermo-chemical environment they are located at. The model comprises all the governing laws of physics (mass, momentum energy and entropy balance) and can offer insights on the mechanics of physics of faults in both environments. The presentation will then focus on real GPS data from the ETS sequences of Cascadia (Canada) and Gisborne (New Zealand), to assess the model's forward predicting capabilities for geophysical applications.