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The role of chemical processes and brittle deformation during shear zone formation and its potential geophysical implications

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Ductile shear zones in the middle and lower continental crust are the locus of interactions between mechanical and chemical processes. Chemical processes encompass metamorphic reactions, fluid-rock interactions, fluid flow and chemical mass-transfer. Studying these processes at the grain scale, and even the atom scale, on exposed inactive shear zones can give insights into large-scale geodynamics phenomena (e.g. crustal growth and mountain building through the reconstruction of P-T-t-D- evolutionary paths. However, other major issues in earth sciences can be tackled through these studies as well. For instance, the mechanism of fluid flow and mass transfer in the deep crust where permeability should be small and transient is still largely debated. Studying exhumed inactive shear zones can also help to interpret several new geophysical observations like (1) the origin of tremor and very low frequency earthquakes observed in the ductile middle and lower crust, (2) mechanisms for generating slow slip events and (3) the physical origin of puzzling crustal anisotropy observed in major active crustal shear zones.

In this contribution, we present a collection of data (deformation, petrology, geochemistry, microtexture) obtained on various shear zones from the Alps that were active within the viscous regime ($T > 450°C$). Our observations show that the development of a shear zone, from its nucleation to its growth and propagation, is not only governed by ductile deformation coeval with reactions but also involves brittle deformation. Although brittle deformation is a very short-lived phenomenon, our petrological and textural observations show that brittle failure is also associated with fluid flow, mass transfer, metasomatic reactions and recrystallization. We speculate that the fluids and the associated mineralogical changes involved during this brittle failure in the ductile crust might play a role in earthquake / tremor triggering below the brittle – ductile transition. Furthermore, the occurrence of micro-fracturing in the ductile crust must have an influence on elastic wave propagation. While in the upper crust, fractures are believed to be the primary contributor to seismic anisotropy, at high pressure, the intrinsic rock Vp and Vs velocities are largely a function of the shape and crystallographic preferred orientation of minerals. However, if microfracturing is involved during ductile deformation, it may have a stronger influence on seismic properties (velocity and anisotropy) than the SPO and CPO of the main mineral phases, particularly if the microfractures are preferentially oriented. Thus, in major active ductile shear zones, like the Main Himalayan Thrust, the speculated transient but pervasive micro-fracturing during ongoing ductile deformation should be considered when interpreting seismic anisotropy.

Finding evidences for brittle deformation, and associated fluid flow, in the ductile crust is a major challenge because many of these textural and mineralogical features tend to be obliterated by the pro-eminent ductile deformation. However, in order to fully understand the causes of some of these geophysical observations, the chemical and physical characterization of exhumed "fossil" ductile shear zones remains essential.