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Shear zones brittle precursors: an expression of brittle deformation and fluid flow in the ductile crust?

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The Earth crust is classically divided into (1) an upper crust characterized by brittle deformation, localized along frictional faults and (2) a mid- to lower crust with a viscous behavior, resulting in the development of ductile shear zones. This simplistic view is now challenged by many field observations, rock physics experiments and seismology, showing that the development of a ductile shear zone from its nucleation to its maturation, involves interactions between brittle and ductile mechanisms, as well as fluid-rock interactions in the ductile realm (e.g. Goncalves et al., 2016; Wehrens et al., 2016). For instance, Mancktelow and Pennacchioni (2005) proposed that shear zones can develop on pre-existing fractures, referred to as shear zones precursors, that can reach several tens of meters in length.

This contribution aims to determine if these fractures (1) are inherited from the late magmatic deformation (cooling joints) and then buried into the ductile domain, or (2) developed at the same depths as the subsequent ductile shear zones. The implications are both (1) rheological, by a further understanding of strain localization in the middle and lower crust; and (2) seismological. Indeed, microseismicity – such as non-volcanic tremors and low frequency earthquakes – has been recorded in the deep extension of major faults (e.g. Nadeau and Dolend, 2005), commonly considered as an aseismic domain. Our work could bring a petrological contribution in the study of these still poorly understood geophysical phenomena.

In order to study these brittle precursors, we selected the Neves area, located in the Tauern tectonic window (Sud-Tyrol, Eastern Alps). This late Variscan (ca. 310-290 Ma) magmatic complex experienced ductile deformation under high pressure conditions during the Alpine event; resulting in more or less developed ductile shear zones, fossilized and exhumed as it stood (e.g. Pennacchioni and Mancktelow, 2007). Thus, preserved immature precursors can be found and sampled.

Petrological observations, show that the initial fracture has been totally recrystallized, thanks to fluid circulation, resulting in an alignment of plagioclase, garnet, biotite, pyrite and quartz. This local mineralogy depends on the host mineral (quartz, plagioclase, biotite). High resolution quantitative X-ray mapping shows three generations of plagioclase based on their composition and textural setting: a saussuritized magmatic plagioclase (I); largely recrystallized into smaller albite-rich grains (II); and a more calcic plagioclase (III), located along the brittle precursor. Phase diagram sections computed for local bulk composition show that plagioclase III crystallization is concomitant with brittle deformation and fluid flow. Plagioclase III is in equilibrium with garnet, epidote and biotite at high temperature and pressure conditions (500-550 °C; 7-8 kbar), i.e. in the middle crust (20-30 km in depth), corresponding to Alpine metamorphic conditions. This result suggests that some of the brittle precursors in the Neves area formed in the ductile crust prior and/or during the development of ductile alpine shear zones. The petrological study of the shear zones brittle precursors brings evidences of brittle-ductile and fluid-rock interactions involved by strain localization in the middle crust.