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The record of deep fluid pressure in veins : a new method based on quartz geochemistry

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Fluids are a primary control on deformation processes, in particular in the upper, brittle portion of the crust. In the mechanical framework of poroelasticity or friction, used to describe brittle rock behavior, the influence of fluid is integrated through the fluid pressure. High fluid pressure reduce the deviatoric stress necessary for slip ; for example during seismic slip, the temperature rise due to frictional work in the fault core might result in a large drop in resistance to further slip and constitutes therefore a very efficient lubricating process. Another example of the influence of fluid pressure is observed in deep slow slip events in subduction zones, where the slipping portion of the plate interface and domains of high fluid pressure migrate conjointly.

While models and observations highlight the large mechanical role of fluid pressure, measurements of fluid pressure below a few kilometers of depths are very indirect and plagued by large uncertainties. Veins constitute one of the ubiquitous by-products of the fluid-rock interaction during deformation at depths. Vein-forming mineral, such as quartz and calcite, trap, as inclusions, the fluid that was present during crystal growth. Fluid inclusions constitute therefore one of the very few record of the physicochemical conditions of the deep fluid.

We examined in this work three examples of syn-deformation quartz veins, from a japanese accretionary complex. The crystals within veins show growth rims, bringing to light the time evolution of the rock-fluid system. Many fluid inclusions are trapped within the growth rims ; in particular methane-rich fluid inclusions, which minimize the problem of late-stage reequilibration and therefore unravel the fluid pressure at the time of trapping. In parallel, those growth rims can be divided into two types, with either low or large content in trace elements (in particular aluminum).

We correlated the median fluid pressure recorded in fluid inclusions with the average Al concentration in quartz : High/low fluid pressure correspond to low/high Al concentration, respectively. Based on literature data about crystal growth in hydrothermal and magmatic contexts, it appears that the higher incorporation of impurities can be accounted for by rapid, out-of-equilibrium growth of quartz. We propose therefore a model of vein evolution with repetitions of large fluid pressure drop, where crystal grew rapidly and incorporated a large concentration in

Al, alternating with longer period of slower growth, at higher fluid pressure, with a reduced incorporation of Al. The highest fluid pressure variations are of the order of 70MPa, and the corresponding Al concentration variations of the order of 0.28wt%.

Quartz veins are abundant in most, if not all tectonic contexts. In addition, Al concentration in quartz is preserved throughout exhumation, unlike fluid inclusions signal, which is in many cases questionable because of reequilibration. In conclusion, quartz geochemistry can be considered as a promising sensor of fluid pressure variations, which can provide access to the conditions of the fluid attending deformation of the brittle crust.