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Age of metamorphic events : petrochronology and hygrochronology

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Geodynamic models of the lithosphere require quantitative data from natural samples. Time is a key parameter: it allows to calculate rates and duration of geological processes and provides informations about the involved physical processes (Vance et al. 2003). Large-scale orogenic models require linking geochronological data with other parameters: structures, kinematics, magmatic and metamorphic petrology (P-T-A-X conditions), thermobarometric evolution of the lithosphere, chemical dynamics (Muller, 2003). This requires geochronometers that are both powerful chemical and petrological tracers. In-situ techniques allow dating a mineral in its petrological-microstructural environment. Getting a "date" has become quite easy... But what do we date in the end ? What is the link between the numbers obtained from the mass spectrometer and the age of the metamorphic event we are trying to date ? How can we transform the date into a geological meaningful age ? What do we learn about the behavior of the geochronometer minerals? Now that we can perform precise dating on very small samples directly in the studied rock, it is important to improve the way we interpret the ages to give them more pertinence in the geodynamic context.

We propose to discuss the Th/U/Pb system isotopic closure in various metamorphic contexts using our published examples of in situ dating on monazite and zircon (Bosse et al. 2009; Didier et al. 2014, 2015). The studied examples show that (i) fluid assisted dissolution-precipitation processes rather than temperature-dependent solid diffusion predominantly govern the closure of the Th/U/Pb system (ii) monazite and zircon are sensitive to the interaction with fluids of specific composition (F, CO_2, K ...), even at low temperature (iii) in the absence of fluids, monazite is able to record HT events and to retain this information in poly-orogenic contexts or during partial melting events (iv) complex chemical and isotopic zonations, well known in monazite, reflect the interaction with the surrounding mineral assemblages. An often neglected observation is that the K-Ar chronometer minerals show similar patterns of isotopic inheritance closely tied to relict patches and heterochemical retrogression phases (Villa and Williams 2013). Isotopic closure in the U-Pb and K-Ar systems follows the same principle: thermal diffusion is very slow, dissolution and reprecipitation are several orders of magnitude faster. This means that both U-Pb and K-Ar mineral chronometers are hygrochronometers. The interpretation of the ages of the different domains cannot be decoupled from the geochemical and petrological context. The focus on petrology also requires, following Villa (1998, 2016), that the ages measured in metamorphic rocks no longer can be used in geodynamic models according to the "closure temperature" concept as originally defined by Dodson (1973).

Bosse et al. (2009) Chem Geol 261: 286
Didier et al. (2014) Chem Geol 381: 206
Didier et al. (2015) Contrib Mineral Petrol 170: 45
Dodson (1973) Contrib Mineral Petrol 40: 259
Muller (2003) EPSL, 206: 237
Villa (1998) Terra Nova 10: 42
Villa (2016) Chem Geol 420: 1
Villa & Williams (2013) In: Harlov & Austrheim (eds.), Metasomatism and the Chemical Transformation of Rock. Springer, p171