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Mylonites of the South Armorican Shear Zone: Insights for crustal-scale fluid flow and water–rock interaction processes

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ABSTRACT

Mylonites display petrographical and geochemical characteristics that can be related to syn-deformation fluid circulation. The South Armorican Shear Zone, a major structural feature of the Armorican Massif (France), is outlined by the presence of mylonitic rocks cropping out mostly in open quarries. These mylonites were essentially formed at the expense of peraluminous granitic bodies. Deformation occurred from ductile conditions in the biotite stability field (>400 °C) down to lower greenschist cataclasis and brecciation, where carbonation developed. U–Pb analyses on zircon and monazite define a minimum duration of 15 Ma for the deformation and hydrothermal history, between 315 Ma and 300 Ma. Fluid circulations are well documented, by way of petrographic observation (chlorite and carbonate crystallization), mineralogical composition analysis (muscovite chemistry), erratic mobility behavior of some elements (As, Sn, U for instance), and stable isotope composition analysis of the infiltrated rocks. High temperature deformation is not accompanied by alteration of the O isotope system, which implies either low fluid/rock ratio and/or the involvement of $\delta^{18}O$ crustal fluids with a composition similar to that of the rocks. On the other hand, some low temperature mylonites show a drastic decrease in the $\delta^{18}O$ values, which has to be related to the influx of surface derived waters. The heat source necessary for this crustal scale downward infiltration of fluids followed by upward motion was likely provided by the exhumation of lower crustal units in the South Armorican domain.

1. Introduction

Information on fluid–rock interaction mechanisms during deformation provides constraints on fluid circulation systems in the middle continental crust, which may in turn shed some light on the global geodynamic evolution of orogenic belts. Crustal-scale shear zones constitute an excellent drain for such fluid circulation because deformation processes can enhance permeability (e.g. Kerrich, 1986; McCaig et al., 1990; Oliver, 1996). As a result, fluids circulating within mid-crustal shear zones lead to rock softening via grain size reduction and dynamic recrystallization, which affects strain localization, rock rheology and the overall thermal structure of the crust (e.g. Barnes et al., 2004; Brodie and Rutter, 1987; Dipple and Ferry, 1992). Consequently, there is a strong interaction between fluid circulation and deformation, both processes enhancing each other. Metasomatism during fluid–rock interaction is also particularly important for the genesis of hydrothermal ore deposits. Indeed, when interacting with deformed rocks, fluids are able to leach out and transport elements toward so-called sinks which, in some cases, may become economically viable.

The present study is focused on the Carboniferous South Armorican Shear Zone (SASZ; Jégouzo, 1980; Fig. 1), which is one of the major structural features observed in the Western European Variscan belt. The SASZ extends for hundreds of kilometers in the Armorican Massif (Fig. 1a) and is geometrically defined by the presence of mylonitized rocks. This region has been extensively studied and is well characterized both on a structural and a tectonic point of view (Berthé et al., 1979; Gapais and Le Corre, 1980; Gumiaux et al., 2004; Jégouzo, 1980; Jégouzo and Rossello, 1988). Conversely, very scarce geochemical and geochronological data exist and the fluid nature and regime in the SASZ have just started to be investigated (Lemarchand et al., 2011).

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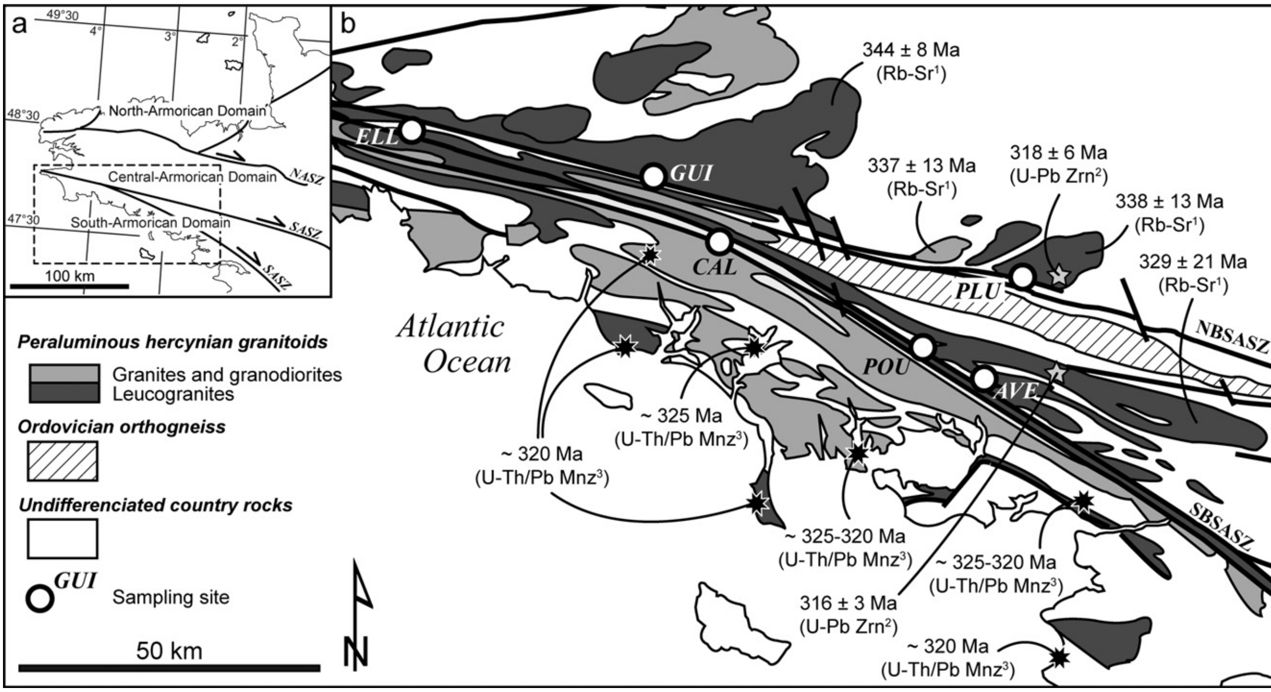

Fig. 1. (a) Location of the studied area in the Armorican Massif, western France. NASZ: North Armorican Shear Zone, SASZ: South Armorican Shear Zone; (b) simplified geological map of the South Armorican system. NBSASZ and SBSASZ: northern and southern branches of the SASZ, respectively. Sampling site names, which correspond to the closest village, are as follows: ELL: Elliant, GUI: Guilligomarc'h, CAL: Calan, POU: Poulmarc'h, PLU: Plumelec, AVE: Saint-Avé. Geochronological data are [1]Whole rock Rb–Sr isochron (Bernard-Griffiths et al., 1985), [2]Zircon U–Pb data (Tartèse et al., 2011) and [3]Monazite U–Th/Pb data (Turrillot, 2010; Turrillot et al., 2009).

The aim of the present study is to provide the geochemical constraints lacking so far for the SASZ. Petrographic observations, whole rock and mineral geochemistry, stable isotope geochemistry and geochronological data of mylonitic rocks sampled in five different sites along the SASZ are presented and interpreted in order to get first order constraints (1) on the fluid regime associated with shearing, (2) on mass transfers and element mobility caused by metasomatism and (3) on the timing of the different events and the resulting geodynamical implications.

2. Geological setting

During Variscan times, the Armorican Massif has undergone deformation related to a major continental collision between Gondwana and Laurussia (e.g. Ballèvre et al., 2009), followed by the development of large dextral shear zones, namely the North Armorican Shear Zone (NASZ) and the South Armorican Shear Zone (SASZ) (Fig. 1a). The SASZ separates two domains within the Armorican Massif which have experienced contrasting metamorphic and structural histories. To the North, the Central Armorican domain consists of a late Proterozoic – early Palaeozoic sedimentary succession, which has been affected by low-grade metamorphism (e.g. Le Corre et al., 1991) with temperatures estimated at around 250–300 °C (illite crystallinity method by Le Corre, 1975; vitrinite reflectance method by Donnot et al., 1973). Westward along the SASZ, higher temperatures were reached during regional metamorphism as recorded by the presence of staurolite-bearing rocks typical of the amphibolite facies (ca. 550 °C; see also Hanmer et al., 1982). From East to West, there is therefore an increase in metamorphic conditions along the northern branch of the SASZ (NBSASZ). In the Central Armorican domain, both strain intensity and metamorphic degree increase southward reaching a maximum on the SASZ itself. To the South lies the South Armorican domain, mainly composed of medium to high-grade micaschists, migmatitic gneisses and anatectic granites (e.g. Brown and Dallmeyer, 1996). These deep crustal units were then exhumed during the extension associated with the chain collapse (Gapais et al., 1993).

The SASZ is divided into two main branches (Fig. 1b). Within the southern branch (SBSASZ) network, a northward-dipping zone corresponding to an early shearing component occurs locally and is enclosed between vertical shear zones. The mylonitic foliation, which bears a 5–10° eastward dipping stretching lineation, is often overprinted by late cataclasis and brecciation. Along this branch, a dextral displacement of ca. 150–200 km has been proposed based on the width of the mylonitized rocks (Jégouzo and Rossello, 1988). The NBSASZ is sub-linear and extends for about 300 km. It displays a subvertical mylonitic foliation also bearing a stretching lineation dipping at ca. 10° eastward. Along this branch, a 40 km minimal dextral offset has been estimated from geometrical reconstructions (Jégouzo and Rossello, 1988).

Syn-kinematic granitic magmatism along the SASZ is attested by the elongated and sigmoidal shape of the plutons (Fig. 1b), strain gradients at the scale of the plutons and the development of S–C structures during cooling (Berthé et al., 1979; Gapais, 1989). Measuring the ages of these granites would thus help to constrain the timing and duration of shearing along the SASZ. However, geochronological data are very sparse. Bernard-Griffiths et al. (1985) published whole rock Rb–Sr isochron ages for some granites emplaced along the SASZ. Along the NBSASZ, ages of the Pontivy, Bignan and Lizio massifs are 344 ± 8 Ma, 337 ± 13 Ma and 338 ± 13 Ma, respectively (Fig. 1b). Along the SBSASZ, the Questembert granite yielded an age of 329 ± 21 Ma. Because of their large uncertainties, these ages are poorly constrained and undistinguishable within error. Therefore these available data only suggest that the SASZ was active during the Early Carboniferous. Recent U–Pb analyses on zircon grains from two samples from the Lizio and Questembert granites yielded younger emplacement ages of 318 ± 6 Ma and 316 ± 3 Ma, respectively (Fig. 1b; Tartèse et al., 2011). These ages are comparable with the numerous monazite U–Th/Pb chemical ages of ca. 325–320 Ma obtained along the south