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$P–T$ paths reconstruction of a collisional event: The example of the Thiviers-Payzac Unit in the Variscan French Massif Central

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Abstract

Because of late metamorphic and tectonic overprints, the reconstruction of prograde parts of $P–T$ paths is often difficult. In the SW Variscan French Massif Central, the Thiviers-Payzac Unit (TPU) is the uppermost allochthon emplaced above underlying units. The TPU experienced a Barrovian metamorphism coeval with a top-to-the-NW ductile shearing (D2 event) in Early Carboniferous times (*ca.* 360–350 Ma). The tectonic setting of the D2 event, compression or synconvergence extension, remains unclear. Using the THERMOCALC software and the model system MnNCKFMASH, the peak $P–T$ conditions are estimated from garnet rims and matrix minerals and the prograde evolution is deduced from garnet core compositions. The combination of these two approaches demonstrates that the TPU experienced pressure and temperature increases before reaching peak conditions at 6.6–9.0 +/− 1.2 kbar and 615–655 +/− 35 °C. This kind of $P–T$ path shows that the regional D2 event corresponds to crustal thickening.

Keywords: $P–T$ path reconstruction; Barrovian metamorphism; Pseudosections; Variscan orogeny; French Massif Central

1. Introduction

A main characteristic of orogens is a polyphase deformation history involving various tectonic processes such as burial of crustal slices followed by exhumation of deep metamorphic rocks by nappe stacking, syn-orogenic to post-orogenic extension and tectonic denudation. The late orogenic processes alter, or even erase, at least part of the early structural, textural and mineralogical features of the metamorphic evolution. Thus, relicts of prograde parageneses and kinematic criteria typical of crustal thickening are often very tenuous. The reconstruction of the prograde part of a $P–T$ path coeval with a compression stage is therefore difficult. However, this problem can be overcome when the metamorphic series contain garnet-bearing metapelitic rocks which have undergone metamorphism with a peak at the amphibolite facies conditions. Indeed, during the prograde history, while most of the minerals in metapelites reach equilibrium at medium temperature because reaction and diffusion rates become high enough to allow the homogenization of phases, garnet tends to preserve its chemical growth zoning. This point is not very relevant for conventional thermobarometry because the minerals which were in equilibrium with the core of the garnet at a given stage of the prograde

Abbreviations: alm, almandine; an, anorthite; ap, apatite; bi, biotite; cel, celadonite; chl, chlorite; cd, cordierite; east, eastonite; g, garnet; gr, graphite; grs, grossular; ksp, K-feldspar; ky, kyanite; ilm, ilmenite; mo, monazite; mu, muscovite; pa, paragonite; pl, plagioclase; pyr, pyrope; q, quartz; rt, rutile; liq, silicate melt; sill, sillimanite; spe, spessartite; st, staurolite; fst, Fe-staurolite; mst, Mg-staurolite; xe, xenotime.

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history have disappeared, or have changed in composition, in response to a *P–T* increase. Even inclusions trapped in garnet are probably no longer in equilibrium with their host mineral because of late exchange processes. On the other hand, as outlined by several authors (*e.g.* Vance and Mahar, 1998; Stowell and Tinkham, 2003), the chemical growth zoning preserved in garnet enables the use of *P–T* pseudosections contoured for garnet composition with different isopleths in order to estimate *P–T* conditions corresponding to garnet nucleation. Each *P–T* pseudosection, calculated with the thermodynamic software THERMOCALC (Powell and Holland, 1988) coupled with its internally consistent thermodynamic database (Holland and Powell, 1998), is valid for a unique chemical composition in a model system. If it can be assumed that the analysed bulk rock composition was the effective chemical composition of the equilibrated system at the time of crystallization of garnet cores, the *P–T* pseudosection drawn for this composition and showing different isopleths for garnet can then be used as a thermobarometric tool allowing the determination of one "point" on the prograde part of the *P–T* path followed by the garnet–bearing metapelites. The second point of the *P–T* path, *i.e.* the peak *P–T* conditions, cannot be determined easily with a pseudosection because the effective chemical composition of the equilibrated system at this highest metamorphic temperature has to be estimated by removing from the whole system those parts of zoned garnet porphyroblasts which were out of equilibrium at that time. Fortunately, when all the phases, except garnet, are homogeneous in the rock, the highest *P–T* conditions can be estimated by using the multi-equilibrium approach of thermobarometry with the mode "average *P–T*" of the software THERMOCALC (Powell and Holland, 1994; Worley and Powell, 2000). Therefore, in short, combining a pseudosection and the results of multi-equilibrium thermobarometry should provide details of at least a part of the prograde *P–T* path followed by garnet metapelites last transformed at the amphibolite facies conditions.

This combined thermobarometric approach is used in the Variscan French Massif Central in order to document the *P–T* evolution of the uppermost tectonic unit, called the Thiviers-Payzac Unit (TPU), emplaced by top-to-the NW ductile shearing above the Upper Gneiss Unit (UGU). The TPU has been chosen as a target for the investigation of the *P–T* path related to top-to-the NW shearing since this crustal slice is little affected by other tectonic events (Faure et al., 1997; Roig and Faure, 2000). In the tectono–metamorphic evolution of the French Massif Central, this top-to-the NW event corresponds to a second tectonic event (D2). In the southern part of the Variscan Belt, the first event (D1) took place during the Early Devonian and corresponds to a top-to-the SW nappe emplacement. This D1 event is related to the collision between Gondwana to the south and Armorica to the north (*e.g.* Matte, 1991; Faure et al., 2004, 2005). The top-to-the NW event (D2) occurred in Late Devonian – Early Carboniferous times and reworks the stack of nappes previously formed by the D1 event. The D2 event is not younger than 350 Ma since the contact between the TPU and its footwall is locally reworked by a sinistral wrench fault coeval with pluton emplacement dated by $^{40}Ar/^{39}Ar$ method on biotite at 346+/−3.5 Ma (Roig et al., 1996). The D2 event has a regional extent since it affects the whole French Massif Central and also the southern part of the Massif Armoricain. However, the geodynamics and tectonic setting of the D2 event are still matter of debate. Indeed, several contradictory models have been proposed to explain the top-to-the NW shearing. The D2 event has been related either to transpressional tectonics during a single orogenic cycle (Brun and Burg, 1982), or to nappe thrusting (Bouchez and Jover, 1986), or to syn-orogenic extension (Mattauer et al., 1988), or to a second compressional cycle after a short period of rifting during Upper Devonian (Faure et al., 1997, 2005). Thus, to reconstruct *P–T* paths experienced by different units is a crucial point to decipher the tectonic setting of the D2 event or, in other words, to know whether the D2 event took place during an extensional tectonic setting or during a compressional one. Indeed, none of the previously exposed models takes into account thermobarometric data. The scarcity of available thermobarometric data concerning the D2 event precludes any interpretation to be correctly assessed. It is also worth underlining that a great part of the tectonic units formed during D1 and D2 events are widely reworked during the Late Carboniferous by syn- and post-orogenic extensional tectonics coeval with the emplacement of numerous granitic plutons (Faure, 1995). Thus, such first hand quantitative information together with a detailed analysis of the thermobarometric results will enable to discuss the tectonic evolution of this part of the Variscan Belt.

2. Geological setting

2.1. Structural framework of the French Massif Central

The Variscan French Massif Central consists of a stack of nappes formed by polyphase tectonics (*e.g.* Matte, 1991; Ledru et al., 1989; Faure et al., 1997, 2005). From south to north, and from bottom to top, the