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Cadomian S-type granites as basement rocks of the Variscan belt (Massif Central, France): Implications for the crustal evolution of the north Gondwana margin

Simon Couzinié [a,b,*], Oscar Laurent [c,1], Marc Poujol [d], Michaël Mintrone [a,1], Cyril Chelle-Michou [a,2], Jean-François Moyen [a], Pierre Bouilhol [e,3], Adrien Vezinet [a,b], Linda Marko [f]

[a] Université de Lyon, Laboratoire Magmas et Volcans, UJM-UCA-CNRS-IRD, 23 rue du Dr. Paul Michelon, 42023 Saint-Etienne, France
[b] University of Stellenbosch, Department of Earth Sciences, Private Bag X1, 7602 Matieland, South Africa
[c] Université de Liège, Département de Géologie B20, Quartier Agora, allée du six Août 12, B-4000 Liège, Belgium
[d] Géosciences Rennes, UMR-CNRS 6118, Université de Rennes I, 35042 Rennes Cedex, France
[e] Department of Earth Sciences, Durham University, Science Labs, Durham DH13LE, United Kingdom
[f] Institut für Geowissenschaften, J.W. Goethe Universität, Altenhöferallee 1, 60438 Frankfurt Am Main, Germany

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ABSTRACT

From the Neoproterozoic to the early Paleozoic, the northern Gondwana margin was sequentially shaped by the *Cadomian* accretionary and the *Variscan* collisional orogens which offers the opportunity to investigate the relative extent of crust production/reworking in both geodynamic settings. In the eastern part of the Variscan French Massif Central (FMC), the Velay Orthogneiss Formation (VOF) represents a consistent lithological unit of the pre-Variscan basement and comprises augen gneisses and leucogneisses. Such rocks constitute a unique record of the pre-Variscan magmatic history and bear critical information on the crustal evolution of the northern Gondwana margin.

Here, we present whole–rock major and trace element compositions indicating that: (i) the VOF shows a remarkable geochemical homogeneity; (ii) the protolith of the augen gneisses corresponds to strongly peraluminous, "S-type" porphyritic granites originating from partial melting of an Ediacaran sedimentary sequence; (iii) the leucogneisses are former leucogranites generated by fractionation of the magma at the origin of the porphyritic granites; and (iv) the whole suite emplaced at shallow crustal levels (<7 km). U–Pb LA–(MC–)ICP–MS analyses on zircon yielded similar emplacement ages of c. 542 Ma and a narrow range of $\varepsilon_{Hf}(t)$ clustering around 0 for the protoliths of both augen and leucogneisses. This homogeneous Hf isotope signature, notably uncommon for S-type granites, would originate from a sequential process of: (i) inherited zircon dissolution during melting and ascent in the crust due to Zr-undersaturated conditions, (ii) isotopic homogenization of the melt by advection and elemental/isotopic diffusion, followed by (iii) early saturation upon emplacement owing to rapid cooling at shallow crustal levels.

We propose that partial melting of Ediacaran sediments occurred during inversion of a Cadomian back-arc basin and was promoted by the high thermal gradient typical of thinned crust domains. Therefore, the VOF and other Cadomian S-type granitoids from the northern Gondwana margin are indicative of substantial crust reworking away from any proper continental collision zone.

1. Introduction

Accretionary orogens develop along oceanic and continental active margins, feature volumetrically abundant mantle-derived magmatism and are accordingly considered as the main locus of continental crust production (Cawood et al., 2009; Jagoutz and Kelemen, 2015; Reymer and Schubert, 1984; Taylor and McLennan, 1985). Conversely, collisional orogens juxtapose stable portions of continental lithospheric blocks and are rather seen as domains of extensive crust reworking through partial melting of pre-existing crustal rocks (Dewey et al., 1986; Harris

* Corresponding author at: Université de Lyon, Laboratoire Magmas et Volcans, UJM-UCA-CNRS-IRD, 23 rue du Dr. Paul Michelon, 42023 Saint-Etienne, France.
E-mail addresses: simon.couzinie@univ-st-etienne.fr, simon.couzinie@ens-lyon.org (S. Couzinié).
[1] Now at Institute for Geochemistry and Petrology, ETH Zürich, Zurich, Switzerland.
[2] Now at School of Earth Sciences, University of Bristol, Bristol BS8 1RJ, UK.
[3] Now at Laboratoire Magmas et Volcans, Université Clermont Auvergne-CNRS-IRD, OPGC, Campus Universitaire des Cézeaux, 6 Avenue Blaise Pascal, 63178 Aubière Cedex, France.

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et al., 1986; Hawkesworth et al., 2009, 2010). However, recent studies have refined and nuanced these end-member scenarios by pointing out that new crust may also be produced at the end of continental collision (Couzinié et al., 2016; Moyen et al., 2017; Niu et al., 2013) and likewise, that crust reworking also takes place in arc systems (Collins and Richards, 2008; Zurbriggen, 2015). Therefore, assessing the relative importance of each phenomenon in both geodynamic settings is paramount to understand the modes of continental crust formation and evolution through time.

Terranes formerly belonging to the northern Gondwana margin (Fig. 1, see review in Stampfli et al., 2013) are ideal targets to address this issue because they have sequentially been affected by: (i) the *Cadomian* Western Pacific-type marginal orogenic system, of Cryogenian–Ediacaran age (Chelle-Michou et al., 2017; Garfunkel, 2015; Linnemann et al., 2014; Nance et al., 1991); followed by, (ii) the *Variscan* orogeny, a major late Paleozoic continental collision episode resulting from the convergence between Laurussia and Gondwana (Kroner and Romer, 2013; Matte, 1986) and culminating with the assembly of Pangea, the latest supercontinent of Earth's history (Rogers and Santosh, 2003).

The French Massif Central (FMC) shows one of the largest exposures of the inner part of the Variscan orogen (Lardeaux et al., 2014) and isotopic evidence from the voluminous Variscan crust-derived granitoids demonstrate that such magmatism extensively reworked a continental crust of Neoproterozoic to early Paleozoic ancestry (Melleton et al., 2010; Moyen et al., 2017; Pin and Duthou, 1990; Turpin et al., 1990). However, the nature of this pre-Variscan crust as well as the geodynamic setting in which it formed is still a matter of debate. For instance, it remains unclear to what extent the crust segment today exposed in the FMC was impacted by the Cadomian orogeny (see discussion in Garfunkel (2015)). From this perspective, a better knowledge of the age, structure, lithological composition and configuration of the pre-Variscan crust in the FMC would: (i) provide new constraints on the late Ediacaran/early Paleozoic paleogeography and geodynamics of the northern Gondwana margin; (ii) improve our understanding of the rate and timing of crustal growth in Western Europe.

In the eastern part of the FMC, the Variscan nappes feature high-grade gneisses and, in particular, large amounts of meta-igneous rocks, which have likely witnessed one or several pre-Variscan magmatic episodes. Somewhat outdated radiometric dating from these orthogneisses (Caen-Vachette, 1979; R'Kha Chaham et al., 1990) as well as detrital and inherited zircon data from metasedimentary rocks (Chelle-Michou et al., 2017) and Variscan granitoids (Laurent et al., 2017) respectively, suggest that they emplaced close to the Proterozoic-Paleozoic boundary at ca. 545 Ma. Yet, these meta-igneous rocks lack modern and/or direct geochronological data, in contrast to the western FMC where such work has been undertaken (Alexandre, 2007; Alexandrov et al., 2001; Melleton et al., 2010). Similarly, the nature, petrogenesis and geodynamic

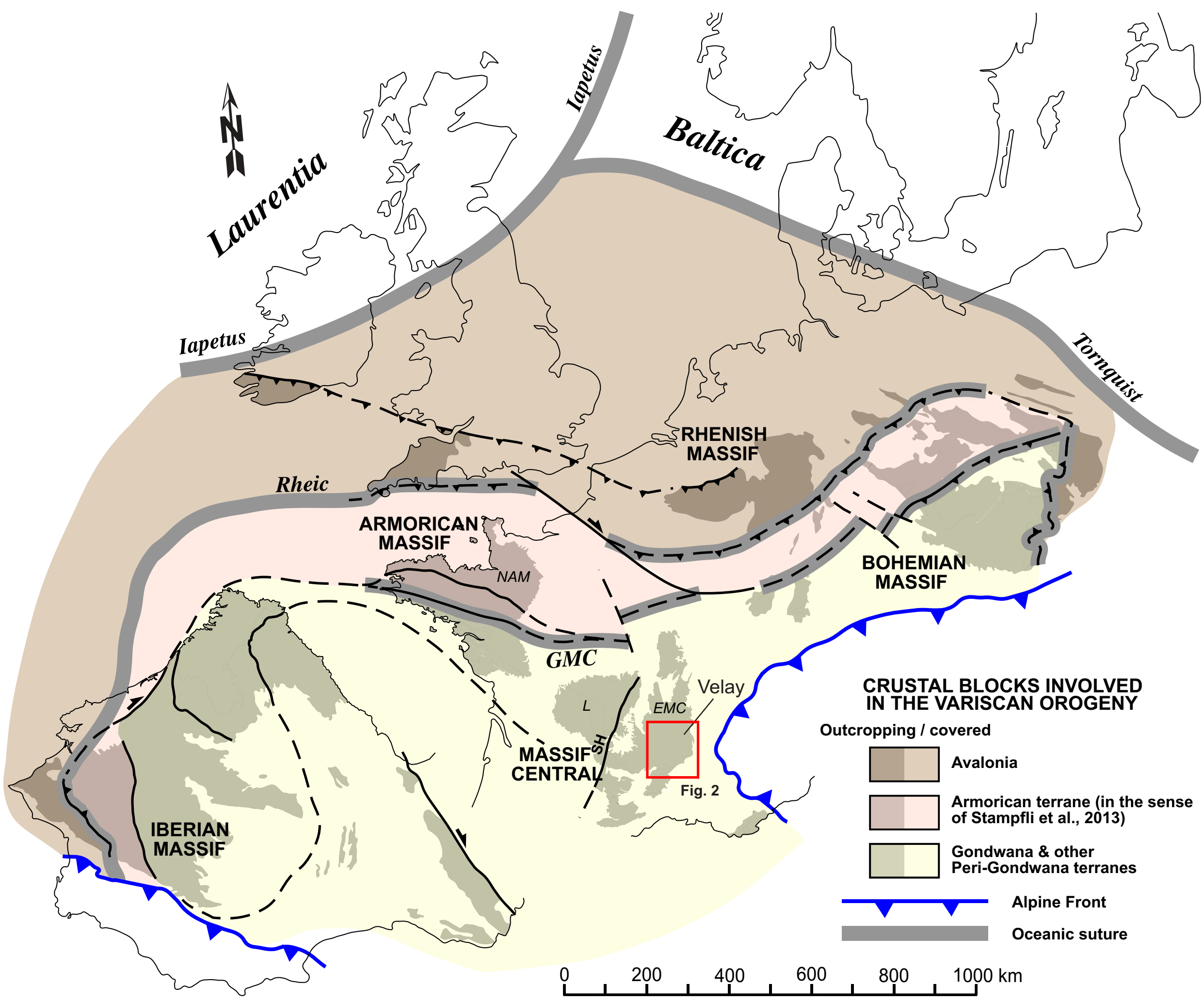

Fig. 1. Sketch map of the crustal blocks involved in the Variscan orogeny, adapted from Ballèvre et al. (2014). Yellow star highlights the location of the study area. Oceanic sutures: GMC, Galicia-Massif-Central Ocean. Regional subdivisions: NAM, North Armorican Massif; L, Limousin (Western Massif Central); EMC, Eastern Massif Central. Shear zones: SH, Sillon Houiller (coal line).