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Thermal imprint of rift-related processes in orogens as recorded in the Pyrenees

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ABSTRACT

The extent to which heat recorded in orogens reflects thermal conditions inherited from previous rift-related processes is still debated and poorly documented. As a case study, we examine the Mauléon basin in the north-western Pyrenees that experienced both extreme crustal thinning and tectonic inversion within a period of ∼30 Myrs. To constrain the time–temperature history of the basin in such a scenario, we provide new detrital zircon fission-track and (U–Th–Sm)/He thermochronology data. The role of rift-related processes in subsequent collision is captured by inverse modeling of our thermochronological data, using relationships between zircon (U–Th–Sm)/He ages and uranium content, combined with thermo-kinematic models of a rift-orogen cycle. We show that the basin recorded significant heating at about 100 Ma characterized by high geothermal gradients (∼80 °C/km). Our thermo-kinematic modeling and geological constraints support the view that subcontinental lithospheric mantle was exhumed at that time below the Mauléon basin. Such a high geothermal gradient lasted 30 Myr after onset of convergence at ∼83 Ma and was relaxed during the collision phase from ∼50 Ma. This study suggests that heat needed for ductile shortening during convergence, is primarily inherited from extension rather than being only related to tectonic and/or sedimentary burial. This should have strong implications on tectonic reconstructions in many collision belts that resulted from inversion of hyper-extended rift basins.

1. Introduction

The steady-state thermal structure of collisional orogenic belts is controlled by upward advection of heat through the coupling between crustal shortening and erosion (Royden, 1993; Stüwe et al., 1994; Willett and Brandon, 2002). However, considering typical thermal relaxation time of several 100 Myrs for thick lithospheres (Jaupart and Mareschal, 2007), transient effects might not be negligible for continental margins that experienced both thermal resetting during thinning and structural inversion over a relatively short period of time (Mouthereau et al., 2013). This process might be even more significant for inverted distal margins that have experienced extreme crustal thinning and mantle exhumation (Manatschal, 2004). The pre-orogenic temperature anomalies caused by crust/subcontinental lithospheric mantle (SCLM) thinning, may therefore significantly impact the thermal history and thermal-dependent ductile mechanisms of deformation in orogens, but their magnitude has yet to be constrained. For instance, Mesalles et al. (2014) using low-temperature thermochronological data in southern Taiwan demonstrated that an originally hot distal margin may record cooling only ∼20 Myrs after the end of rifting due to the onset of continental accretion.

Here, we focus on the Pyrenees, where geochronological and petrographic constraints indicate that rifting exhumed the SCLM in Albian times (ca. ∼110 Ma) (Vielzeuf and Kornprobst, 1984; Lagabrielle and Bodinier, 2008; Jammes et al., 2009; Lagabrielle et al., 2010; Clerc et al., 2012) while plate convergence initiated at ∼83 Ma (Rosenbaum et al., 2002). The Mesozoic Mauléon basin in

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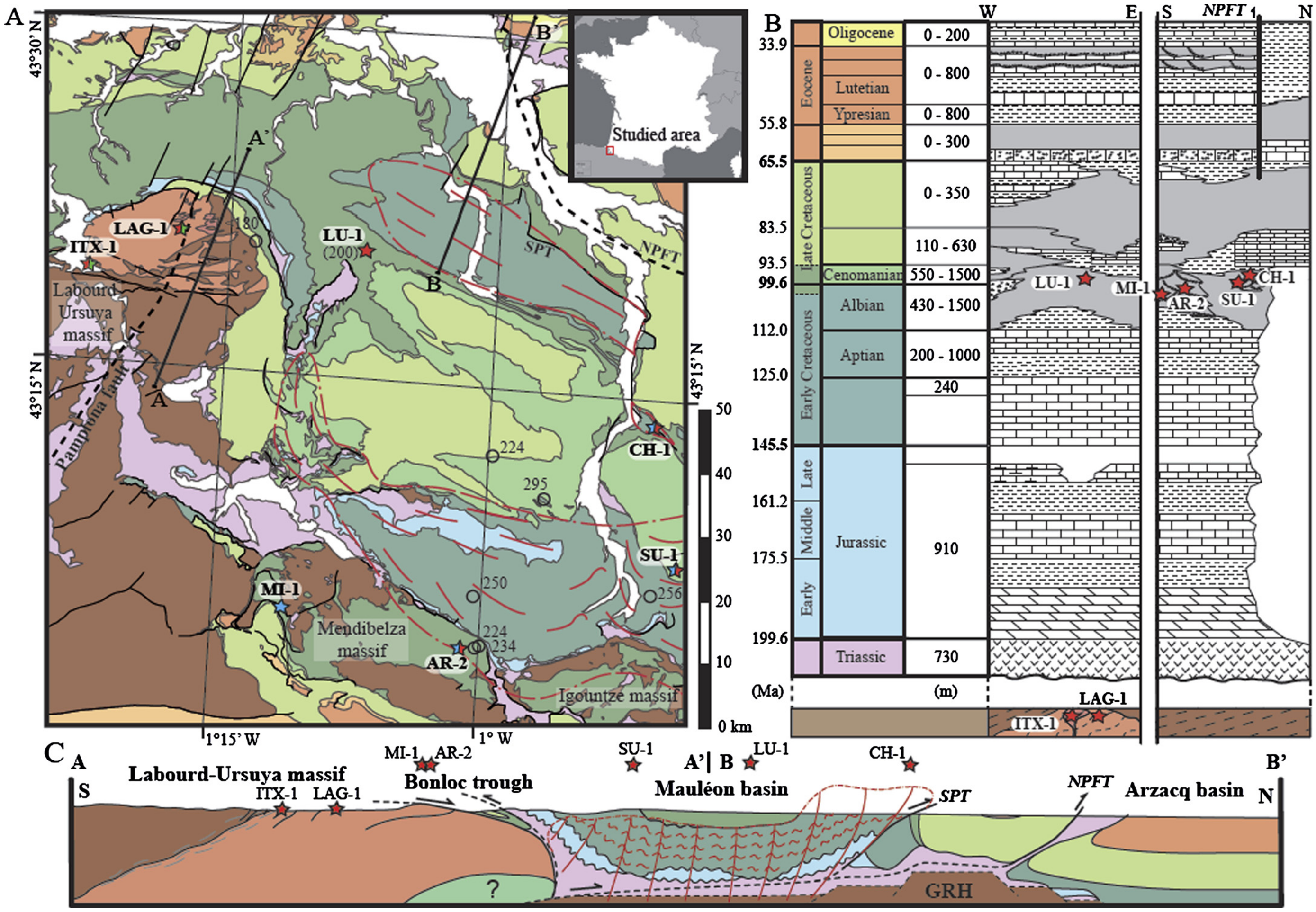

Fig. 1. A) Geologic map of the study area. Red stars and circles depict the position of studied samples and samples from which RSCM temperatures were obtained (Clerc and Lagabrielle, 2014), including one new estimate from this study (Lu-1), respectively. The extent of cleavage domain is shown as red dashed area. B) Synthetic lithostratigraphy of meso-cenozoic successions of the Mauléon basin and layer thickness inferred from borehole data (Fig. 5B). C) Geological cross-section of the western part of the Mauléon basin, including the location of samples and the extent of cleavage domain, same as shown in A. Note that the ductile deformation domain is observed at the base of the basin. NPFT: North Pyrenean Frontal Thrust, SPT: Saint-Palais Thrust, GRH: Grand-Rieu High. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

the north-western Pyrenees (Fig. 1A) is interpreted as a preserved hyper-extended rift system formed during the Late Aptian–Early Albian, above a low-angle detachment system (Johnson and Hall, 1989; Jammes et al., 2009; Masini et al., 2014). This is supported by field evidences of breccias of mantle peridotites reworked in syn-/post-rift sediments of Albo-Cenomanian age, or tectonically overlying the granulitic complex of the Labourd–Ursuya Massif (Jammes et al., 2009).

To establish the time–temperature history of the Mauléon basin, we inverse modeled detrital zircon fission-track and (U–Th–Sm)/He thermochronological data collected for this study. Model results were then compared to thermal patterns predicted from a 1D thermo-kinematic numerical model of the evolution of hyper-extended rift basins that are inverted during collision. Our results reveal that high geothermal gradients, inherited from hyper-extension, are maintained over 30 Myrs after convergence initiated.

2. Hyper-extension in the Pyrenees and thermal constraints

The Pyrenean belt resulted from the inversion of previously extended domains of the Iberian and European plates from the Late Cretaceous to the Late Oligocene (Choukroune et al., 1989 and references therein). The Mauléon basin, located in the western part of the North Pyrenean Zone, consists of folded Mesozoic sedimentary units, thrust northward during the Tertiary along the Saint-Palais Thrust and the North-Pyrenean Frontal Thrust (Fig. 1). The basin is a Late Aptian to Albo-Cenomanian sag basin interpreted as a hyper-extended rift basin formed above a low-angle extensional detachment system, which is identified on the northern flank of the Labourd–Ursuya massif (Jammes et al., 2009) and at the base of the Igountze–Mendibelza massif (Johnson and Hall, 1989). In such a hyper-extended system, middle–lower crustal rocks and the SCLM were exhumed (Jammes et al., 2009; Masini et al., 2014), but age constraints on the timing of exhumation are still lacking. The only age associated to this extension phase is obtained in the eastern part of the Mauléon basin, where a gabbroic dyke, intruding the exhumed mantle body of Urdach, is sealed by Cenomanian sediments (Jammes et al., 2009; Debroas et al., 2010), and yields a relative flat Ar–Ar on biotite spectrum in the 105–108 Ma range (Masini et al., 2014).

Alkaline magmatism, high-temperature (up to 600 °C) low-pressure (HT-LP) metamorphism (Montigny et al., 1986; Golberg and Leyreloup, 1990), and hydrothermal fluid circulation associated with talc-chlorite mineralization (Boulvais et al., 2006) are observed elsewhere in the North Pyrenean Zone. These constraints indicate a heating episode from 110 Ma to 85 Ma (Montigny et al., 1986). Raman spectroscopy of carbonaceous material (RSCM) shows that the Albian to Cenomanian series of the Mauléon basin experienced shallow to mid-crustal temperatures of 180 to 295 °C (Clerc and Lagabrielle, 2014). Determining whether these tempera-