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Very high geothermal gradient during mantle exhumation recorded in mylonitic marbles and carbonate breccias from a Mesozoic Pyrenean palaeomargin (Lherz area, North Pyrenean Zone, France)

Yves Lagabrielle [a,*], Camille Clerc [b], Alain Vauchez [c], Abdeltif Lahfid [d], Pierre Labaume [c], Bernard Azambre [e], Serge Fourcade [a], Jean-Marie Dautria [c]

[a] Géosciences Rennes, CNRS-UMR 6118, Université de Rennes-1, Campus de Beaulieu, 35042 Rennes cedex, France
[b] ISTO, CNRS-UMR 7327, 1A, rue de la Férollerie, 45071 Orléans cedex 2, France
[c] Géosciences Montpellier, CNRS-UMR 5243, Université de Montpellier, place Eugène-Bataillon, 34095 Montpellier, France
[d] BRGM/LMA/MIN, 3, avenue Claude-Guillemin, 45000 Orléans, France
[e] Institut des sciences de la terre de Paris, 5, place Jussieu, 75005 Paris, France

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ABSTRACT

Although they are famous among Earth scientists, the Lherz peridotites are exposed within geological formations of the North Pyrenean Zone (NPZ) still lacking detailed investigations. Our study focuses on the metasediments of the Aulus basin hosting the Lherz peridotite body and associated ultramafic fragments of smaller size. The new data set comprises of structural analysis and detailed geological mapping of the massive Mesozoic marbles that form the prerift sequence typical of the NPZ and of the ultramafic-rich clastic breccia formations surrounding the peridotite bodies. The massive marbles display an evolution from hot and ductile to cold and brittle deformation, indicative of an exhumation process ending with the sedimentary reworking of both the deformed Mesozoic metasediments and the exhumed ultramafic rocks. Crystal Preferred Orientations (CPO) measured in the marbles support a deformation mechanism by dislocation creep of calcite, which is dominant between 400 °C and 600 °C; these deformation temperatures are within the range determined earlier by Clerc et al. (2015), using RSCM (Raman Spectroscopy of Carbonaceous Material) geothermometry. As a consequence, we better describe the transition from ductile to brittle deformation in the prerift marbles and clarify the origin of the syn-rift breccias. Due to continuous exhumation along detachments' faults, the brecciated metamorphic carbonates of the prerift NPZ sedimentary cover were passively uplifted towards shallower levels and progressively unroofed, while transported passively on the back of the exhumed ultramafic footwall. These results are consistent with the recent interpretations of the North Pyrenean peridotites as remnants of subcontinental mantle rocks exhumed within the pre-Pyrenean rift system. We emphasize the importance of tectonic decoupling between the Mesozoic sedimentary cover and the Palaeozoic basement, which leads to the juxtaposition of metamorphosed and deformed Mesozoic

* Corresponding author.
E-mail address: yveslagabrielle@yahoo.fr (Y. Lagabrielle).

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sediments directly on top of exhumed mantle rocks. We favor a model of tectonic denudation of the peridotites below prerift sediments metamorphosed during the extension of the basin floor under high temperatures and in a thermal regime characterized by a very high gradient.

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1. Introduction

About forty small fragments of subcontinental, variably serpentinized lherzolites are spread along the Pyrenean chain. They are concentrated in a narrow belt of Mesozoic sediments forming the North Pyrenean Zone (NPZ) parallel to the North Pyrenean Fault (NPF), which represents the major tectonic boundary between the Eurasian and Iberian plates (Choukroune and ECORS Team, 1989; Muñoz, 1992; Roure and Choukroune, 1998; Teixell, 1998). The peridotites are locally associated with tectonic slices of lower crustal material, which exhibit granulitic paragenesis (Vielzeuf, 1984; Vielzeuf and Kornprobst, 1984). The NPZ corresponds to an alignment of inverted basins that deepened during Albian–Cenomanian times in response to the transtensional motion along the future NPF during the counterclockwise rotation of Iberia (Gong et al., 2008; Olivet, 1996; Sibuet et al., 2004). Various models have been proposed to explain the occurrence of small mantle fragments in the NPZ. They involve opposite processes ranging from tectonic intrusions into sediments (Minnigh et al., 1980; Vielzeuf and Kornprobst, 1984) to tectono-sedimentary reworking of previously exhumed mantle rocks (Choukroune, 1973). Recent studies favor a tectono-sedimentary model for the emplacement of the ultramafic rocks and associated breccias (Clerc and Lagabrielle, 2014; Clerc et al., 2012; Jammes et al., 2009, 2010; Lagabrielle and Bodinier, 2008; Lagabrielle et al., 2010; Mouthereau et al., 2014; Saint Blanquat et al., 2016). In these models, the subcontinental Pyrenean mantle has been exhumed along detachment faults and exposed locally on the floor of the narrow NPZ basins during the Mid-Cretaceous rifting period.

Since they recorded crucial events in relation with the Cretaceous extension, the prerift sediments of the NPZ represent important targets for geological investigations related to mantle exhumation processes. This study is aimed at characterizing the metamorphic and deformation history of the Mesozoic sediments of the Aulus basin (Haute-Ariège) in relation with the tectonic processes accompanying mantle exhumation. We investigate the transition from ductile to brittle deformation of metasediments during exhumation and their subsequent brecciation within the Aulus basin on the basis of a new detailed geological mapping of the metasedimentary formations coupled with the first microstructural analysis of the massive deformed carbonates.

2. Geological setting of the Lherz ultramafic bodies

Two major peridotite bodies outcrop in the Aulus basin, at the Étang de Lherz and in the Freychinède forest (Fig. 1). They occur within a narrow band of Mesozoic metasediments pinched and verticalized between two units exposing the Palaeozoic continental crust: the Axial Zone to the south and the Trois Seigneurs massif to the north. The Étang de Lherz subcontinental peridotites derive from the refertilization of an old (~2.5 Ga) harzburgitic lithosphere by mantle-derived melts (Bodinier et al., 1988; Le Roux et al., 2007), possibly during Late Variscan times (Pin and Vielzeuf, 1983). The ultramafic rocks of the Aulus basin are included within a High Temperature–Low Pressure (HT–LP) metamorphic belt that developed between 110 and 85 Ma (Albarède and Michard-Vitrac, 1978; Clerc et al., 2015; Golberg and Maluski, 1988; Montigny et al., 1986) with *P*–*T* conditions estimated at 500–650 °C for 300–400 MPa (Bernus-Maury, 1984; Golberg and Leyreloup, 1990), to 50–150 MPa, in accordance with a maximum stratigraphic thickness of 3–4 km (Goujou et al., 1988).

3. The metasedimentary formations of the Aulus basin

The Mesozoic metasediments of the Aulus basin are massive carbonates, often mylonitic, and monomictic to polymictic carbonate breccias (Choukroune, 1973, 1976; Colchen et al., 1997; Ternet et al., 1997; Fig. 1). Our detailed mapping indicates that the contacts between these two rock types consist alternatively of an abrupt juxtaposition by fault or of a progressive transition, as described further in this section. At the basin scale, the largest units of massive carbonates are found in the eastern and western part of the Aulus basin, whereas the carbonate-ultramafic polymictic breccias are dominant in the core of the basin (Fig. 2).

3.1. The massive carbonates

Despite an important imprint of the HT–LP metamorphism, the overall stratigraphy of the Aulus massive metasediments is well established. The original sedimentary sequence includes dominant Triassic to Aptian carbonates and minor black metapelites. Some fossils are well preserved in Liassic dolostones (Col Dret and Vallon de Saleix: Carez, 1901; Colchen et al., 1997; Ternet et al., 1997). All the metasediments display clear evidence of ductile deformation with bedding-parallel foliation (Fig. 3). The most abundant lithologies are Late Jurassic to Aptian banded marbles with alternating white to bluish-gray centimeter-thick layers, locally stretched, showing millimetric to decametric recumbent folds. Middle Liassic banded metasediments are composed of alternating millimeter-thick layers of brown marbles and metapelites

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