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Basement – Cover decoupling and progressive exhumation of metamorphic sediments at hot rifted margin. Insights from the Northeastern Pyrenean analog

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ABSTRACT

We compile field data collected along the eastern part of the North Pyrenean Zone (NPZ) to point to a tectonic evolution under peculiar thermal conditions applying to the basin sediments in relation with the opening of the Cretaceous Pyrenean rift. Based on this compilation, we show that when thinning of the continental crust increased, isotherms moved closer to the surface with the result that the brittle-ductile transition propagated upward and reached sediments deposited at the early stage of the basin opening. During the continental breakup, the pre-rift Mesozoic cover was efficiently decoupled from the Paleozoic basement along the Triassic evaporite level and underwent drastic ductile thinning and boudinage. We suggest that the upper Albian and upper Cretaceous flysches acted as a blanket allowing temperature increase in the mobile pre-rift cover. Finally, we show that continuous spreading of the basin floor triggered the exhumation of the metamorphic, ductily sheared pre-rift cover, thus contributing to the progressive thinning of the sedimentary pile. In a second step, we investigate the detailed geological records of such a hot regime evolution along a reference-section of the eastern NPZ. We propose a balanced restoration from the Mouthoumet basement massif (north) to the Boucheville Albian basin (south). This section shows a north to south increase in the HT Pyrenean imprint from almost no metamorphic recrystallization to more than 600 °C in the pre- and syn-rift sediments. From this reconstruction, we propose a scenario of tectonic thinning involving the exhumation of the pre-rift cover by the activation of various detachment surfaces at different levels in the sedimentary pile. In a third step, examination of the architecture of current distal passive margin domains provides confident comparison between the Pyrenean case and modern analogs. Finally, we propose a general evolutionary model for the pre-rift sequence of the Northeastern Pyrenean rifted margin.

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1. Introduction

The Cretaceous basins of the North Pyrenean Zone (NPZ), a case study of synchronous sedimentation and syn-metamorphic HT-LP deformation.

Recent studies of continental passive margins collectively describe a great variety of processes accounting for the extreme thinning of the continental crust. Among all the parameters that may act during crustal stretching, the thermal state of the system and the temporal evolution of the heat distribution during thinning appear of major importance. An important issue is thus to better describe the thermal conditions of a variety of passive margins, including inverted passive margins in orogens where the most distal portions of the system is often well exposed. The Pyrenees are now known to expose remarkably well-preserved sections representative of most of the domains constituting inverted mid-Cretaceous continental passive margins, from the external domains to the domain of exhumed mantle (refs). Moreover, a specific model of continental thinning and breakup under high thermal conditions has been recently proposed to account for a number of geological features of the North Pyrenean Zone (NPZ) (Fig. 1; Clerc and Lagabrielle, 2014). This model applies to the internal part of the mid-Cretaceous Pyrenean rift and differs significantly from models of cold passive margins (i.e.: Type I model of Huismans and Beaumont, 2011; Huismans

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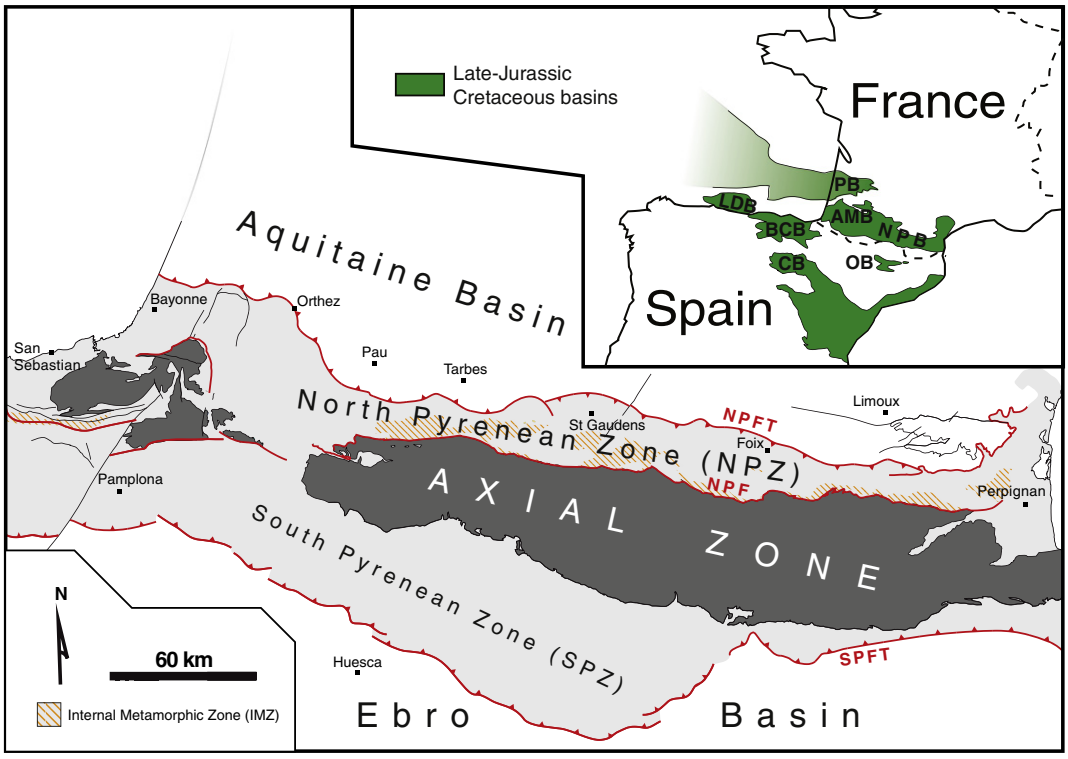

Fig. 1. Structural sketch of the Pyrenean range. NPFT: North Pyrenean Frontal Thrust, NPF: North Pyrenean Fault, SPFT: South Pyrenean Frontal Thrust.

and Beaumont, 2014). It implies that during stretching, the thinned continental crust is extracted horizontally from its original location between the pre-rift sediments and the sub-continental mantle. When thinning increases, isotherms move closer to the surface so that the brittle-ductile transition propagates upward and reaches sediments deposited at the early stage of the basin opening. This model accounts for the early tectonic contact between exhumed mantle rocks and pre-rift sediments and for the ductile deformation of the pre-rift sediments under HT-LP conditions well observed along the Internal Metamorphic Zone (IMZ) of the NPZ. In the following, we shed light on two major geological features of the IMZ that can be summarized as follows: (1) syn-rift, Albian-to Turonian flysch sequences were deposited while the carbonate pre-rift sequences were ductily deformed in the deepest parts of the basins, and (2) all along the IMZ, the Mesozoic strata recorded a high-temperature metamorphic event dated from the Albian to Coniacian, indicating a long lasting thermal anomaly and continuous flysch sedimentation (e.g. Vacherat et al., 2014; Clerc et al., 2015). Such a synchronicity between flysch sedimentation and HT metamorphism at depth is not commonly described is the literature. This leads us to examine how tectonics, metamorphism and sedimentation may be active in a single basin during continental extension leading to mantle exhumation. This work outlines how geological investigations in inland analogs may help better understanding the poorly known architecture and lithology of distal continental margins.

2. The NPZ as an analog of distal passive margins

The Pyrenean belt is the result of the convergence between the Iberia and the Europa plates, which started during the late Cretaceous (late Santonian) and ended during the early Miocene. Geological and geophysical studies have shown that the belt forms an asymmetric double-verging tectonic wedge above the north-dipping Iberian continental lithosphere (e.g. Choukroune and ECORS Team, 1989; Roure et al., 1989; Muñoz, 1992; Vergés et al., 1995; Teixell, 1998; Teixell et al., 2016). The Pyrenean convergence resulted in the inversion of the rifted domain that separated the Iberia and Europe continents from the late Aptian to the late Santonian. However, the paleogeographic reconstruction of the plate pattern remains a subject of major debate, with two end-member kinematic models describing the motion of Iberia with respect to Europe during rifting: (1) a scissor-type opening model for the Bay of Biscay (Srivastava et al., 2000, Rosenbaum et al., 2002; Sibuet, 2004), and (2) a left-lateral strike-slip opening model (Le Pichon et al., 1970; Choukroune and Mattauer, 1978; Olivet, 1996; Stampfli et al., 2002; Jammes et al., 2009; Handy et al., 2010). Due to such discrepancies between existing models, there is still a debate regarding the maximum width of the domain opened between the Iberia and the Europa plates and the timing and amount of strike-slip movement. The maximum basin width was proposed by Vissers and Meijer (2012), with 300 km of mantle-dominated ocean floor exhumed during the late Jurassic and early Cretaceous, then subducted during the inversion. On the other hand, the model of dominant strike-slip motion involves the opening of numerous narrow pull-apart basins (Choukroune and Mattauer, 1978). However, in the most recent models, there is a general agreement that the movement of Iberia relative to Europe was accommodated within a wide, diffuse plate boundary along which E-W trending transtensional basins opened (Jammes et al., 2009, 2010; Tugend et al., 2014). In this view, the Cretaceous rift system must be considered as integrating not only the inverted North Pyrenean basins, but also the Los Cameros, Organya, Arzacq, Parentis and the Basque-Cantabrian basins, which correspond to a present-day width of 360 km extending up to circa 500 km when restored before the Pyrenean shortening.

The Paleozoic rocks forming the basement of the Meso-Cenozoic sediments involved in the Pyrenean belt are mainly exposed in the central part where they form the high elevation Axial Zone. The Axial Zone is bounded to the north by the ~EW-trending North Pyrenean Fault (NPF). North of this fault, the North Pyrenean Zone (NPZ) is a narrow belt of Mesozoic sediments and Paleozoic massifs running over ~400 km all along the range (Bertrand, 1940; Mattauer, 1968; Mattauer and Henry, 1974; Fig. 2). The NPZ represents the main system of inverted sedimentary basins that opened between Iberia and Europa during the Cretaceous rifting.

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