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On the origin of cleavage in the Central Pyrenees: Structural and paleo-thermal study

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ABSTRACT

The present work provides a combined structural and paleothermal (fluid inclusions, illite content in mixed layers illite–smectite, Kübler index and vitrinite reflectance) investigation of the Alpine cleavage domain affecting the western South Pyrenean Zone (Central Pyrenees). Integration of structural and paleothermal data allows us (i) to determine the position of the cleavage front in the sedimentary sequence and (ii) to define mechanisms and temperature conditions for cleavage development.

Cleavage in the eastern part of the study area is approximately limited to the forelimb of the Gavarnie hanging wall anticline, but to the West it extends progressively southwards, affecting younger turbiditic units. At regional scale, the cleavage front is oblique to the strike of bedding and the overall trend of macrostructures. Pressure-solution is the main mechanism for cleavage development, and a strong thermal control on the position of the cleavage front is inferred. The transition between sedimentary and tectonic, compressional fabric is marked by vitrinite reflectance values of 1.12–1.14%, Kübler index values between 0.71 and 0.74°Δ2θ and the transition between R1 and R3 mixed layers illite–smectite. A lower thermal boundary of 140–160 °C is suggested for incipient cleavage development in the shaly beds of the turbiditic sequence, as well as an upper boundary constrained by a maximum measured value of about 215 °C.

1. Introduction

Internal deformation accompanying folding and thrusting can be macroscopically recognized by the development of cleavage planes. In this sense, the onset of internal deformation at the mesoscopic-scale can be defined by the cleavage front, or boundary between cleaved and un-cleaved rocks. The position of the cleavage front depends on lithological and structural factors, and is intimately related to paleo-thermal and burial conditions occurring during deformation (Holl and Anastasio, 1995). Previous studies on sedimentary and low-grade metamorphic rocks have pointed out that the development of cleavage occurs under different temperatures ranging between 175 and 300 °C, depending on the lithology (195 °C in mudstones, Holl and Anastasio, 1995; 175 °C in limestones, Groshong et al., 1984; 300 °C in shales and siliciclastic rocks, Elliott, 1973; Lee DiTullio et al., 1993).

The Pyrenean range is a good natural laboratory for investigating the paleo-thermal conditions needed for cleavage development in sedimentary rocks. The Pyrenees are constituted by thrust sheets involving Paleozoic basement rocks and Meso-Cenozoic cover units (Séguret, 1972; Williams and Fischer, 1984; Roure et al., 1989; Mattauer, 1990; Muñoz, 1992; Puigdefàbregas et al., 1992; Teixell, 1992, 1996; Vergés et al., 1995 among others) and showing the superimposition of a heterogeneously developed cleavage of Alpine age. In the Axial and South Pyrenean Zones (SPZ, Fig. 1a), the presence of Alpine cleavage has been recognized for decades but never accounted for in detail. Cleavage in this area extends from the Axial Zone to the Eocene turbidites of the Jaca Basin (Choukroune and Séguret, 1973; Fig. 1a). The cleavage front is always located within the same stratigraphic unit (the Eocene turbidites) and therefore, the influence of lithological factors affecting its position can be considered negligible.

The present work contributes in the understanding of cleavage development in the South Pyrenean Zone by providing new structural and paleothermal data. A detailed study of the position of the cleavage front within the stratigraphic sequence is presented and discussed with respect to previous studies (Choukroune and

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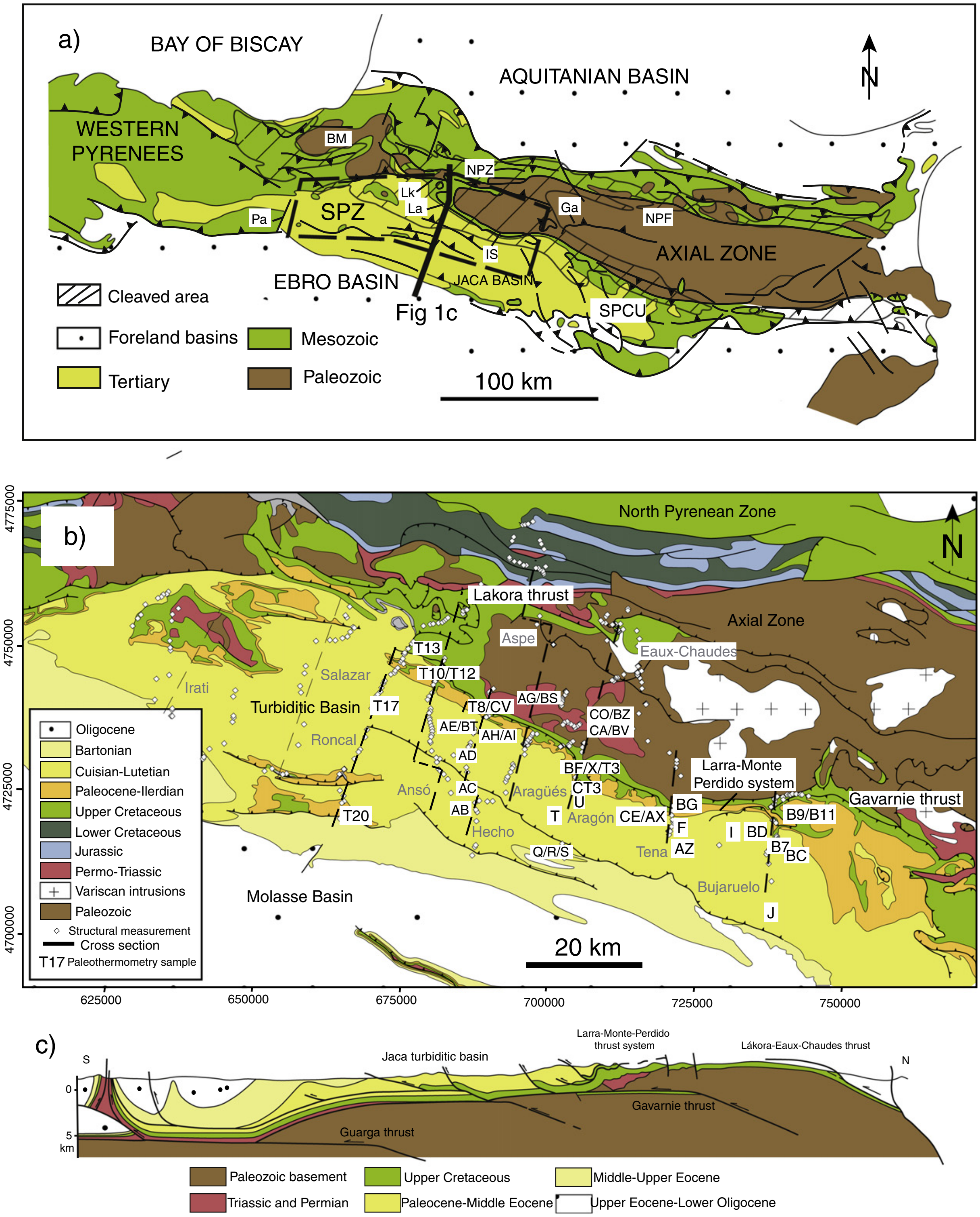

Fig. 1. a) Simplified geological map of the Pyrenees (modified from Teixell, 1996) with location of the study area (dashed box). Cleavage domain mapping modified from Choukroune and Séguret (1973). The trace of the cross section in Fig. 1c is indicated. Lk, Lákora thrust; La, Larra thrust; Pa, Pamplona fault; Ga, Gavarnie thrust; Is, Internal Sierras; NPZ, North Pyrenean Zone; NPF, North Pyrenean Fault; SPCU, South Pyrenean Central Unit; SPZ, South Pyrenean Zone; BM, Basque Massifs. UTM coordinates are shown. b) Geological map of the studied area (simplified and modified from Barnolas et al., 2008). Location of structural measurements, sampling sites for paleo-thermal analyses and trace of cross sections in Fig. 6 are shown. c) The Ansó cross-section, in the western part of the Internal Sierras (modified from Teixell, 1996; the northermost part of the cross-section is not shown).

Séguret, 1973; Labaume et al., 1985) and a first paleothermal investigation of fluid inclusion microthermometry on tectonic veins, X-ray diffraction (XRD) analyses on clay-size fraction of sediments and optical study on dispersed organic matter was carried out and integrated with structural data.

2. Geological setting

The Pyrenees are the result of the collision of the Iberian and Eurasian plates during Late Cretaceous and Tertiary times. They are an excellent natural example of double vergent belt constituted by an