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Late Pleistocene folding above the Mail Arrouy Thrust, North-Western Pyrenees (France)

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ABSTRACT

The Western Pyrenees have experienced several major earthquakes in the last 400 years. Herein, we investigate the ongoing tectonic activity of the Arudy area affected by one of the largest earthquakes (M = 5.1; 1980) registered in the instrumental seismicity catalogue in the Western Pyrenees. Folding of alluvial terraces younger than 17 +/− 3 ky above the Mail Arrouy Thrust (MAT), Attest from a Late Pleistocene tectonic activity. This deformation resulted in a shallow fold with a wavelength of 2800 m and amplitude of 7 to 8 m. The MAT is rooted above a former normal fault of the Cretaceous Iberian margin, which is a potential seismogenic source.
Such observations suggest that the northern flank of the Western Pyrenees is still subjected to shortening in response to a compressional stress regime. This compression is consistent with the African-Eurasian plate kinematics and the Arudy 1980 earthquake. Nonetheless, recent seismological data suggest the presence of an extensional stress regime in the range. This extension is indicated by some seismic events mostly observed in the Pyrenean high chain. Our hypothesis is that these extension-driven events could be due to a local stress-field induced by the elevation of the range. On the contrary, the compression, associated with the regional stress regime, could prevail in the outermost domain of the range.

1. Introduction

We focus here on the Western Pyrenees where the seismic activity is moderate but persistent (Fig. 1; Rigo et al., 2005; Souriau and Pauchet, 1998). The seismicity is mainly aligned along an east–west direction, and the nodal solutions reveal a predominantly dextral strike–slip faulting (Delouis et al., 1993; Nicolas et al., 1990; Souriau et al., 2001). Historical seismicity also emphasizes the significance of the seismic activity of the area. Two historical earthquakes occurred in 1660 and 1750 in the Lourdes Valley with intensities of IX and VIII (Lambert et al., 1996). These events caused significant damage in the cities of Bagnères-de-Bigorre and Lourdes but their fault sources have not yet been identified.

On the 13th of August 1967, the Arette earthquake was the first destructive event recorded in the western Pyrenees. Its magnitude ranged between 5.3 and 5.7 (Fig. 1; Souriau et al., 2001), however, a precise and exhaustive seismotectonic study could not be completed due to the bad instrumentation in the area. Improvement of the seismological networks (see e.g. Souriau and Pauchet, 1998; Souriau et al., 2001) allowed to better constrain the mechanisms of later events in 1980 (Arudy), 2002 (Cauteret (ML = 4.6; Dubos et al., 2004)) and 2006 (Lourdes (ML = 5.0; Sylvander et al., 2008)). The fault–slips associated to such events are small, a few centimeters.

A major question in this context deals with the identification of active fault sources. Due to the very low strain rates (<0.1 mm/yr; Nocquet and Calais, 2004), pieces of geomorphic evidence of tectonic activity are weak. Moreover, vegetation cover, human activity and the strong glacial reshaping during the Quaternary have masked possible geomorphic signal. Thus, comprehensive seismotectonics studies are sparse in the western and central Pyrenees (e.g. Alasset and Meghraoui, 2005; Courjault-Radé et al., 2009; Dubos-Sallée et al., 2007; Ortuño et al., 2008).

After a critical revision of former works, we identify a potential fault source in the Mail Arrouy Thrust (MAT) located in the Arudy epicentral area. Using alluvial terraces coupled with near surface geophysical imagery, we found evidence for recent reactivation. The morphotectonic context led to the implementation of a specific methodology that we present herein. We then discuss these new observations in the context of the seismotectonic setting of the Pyrenees.

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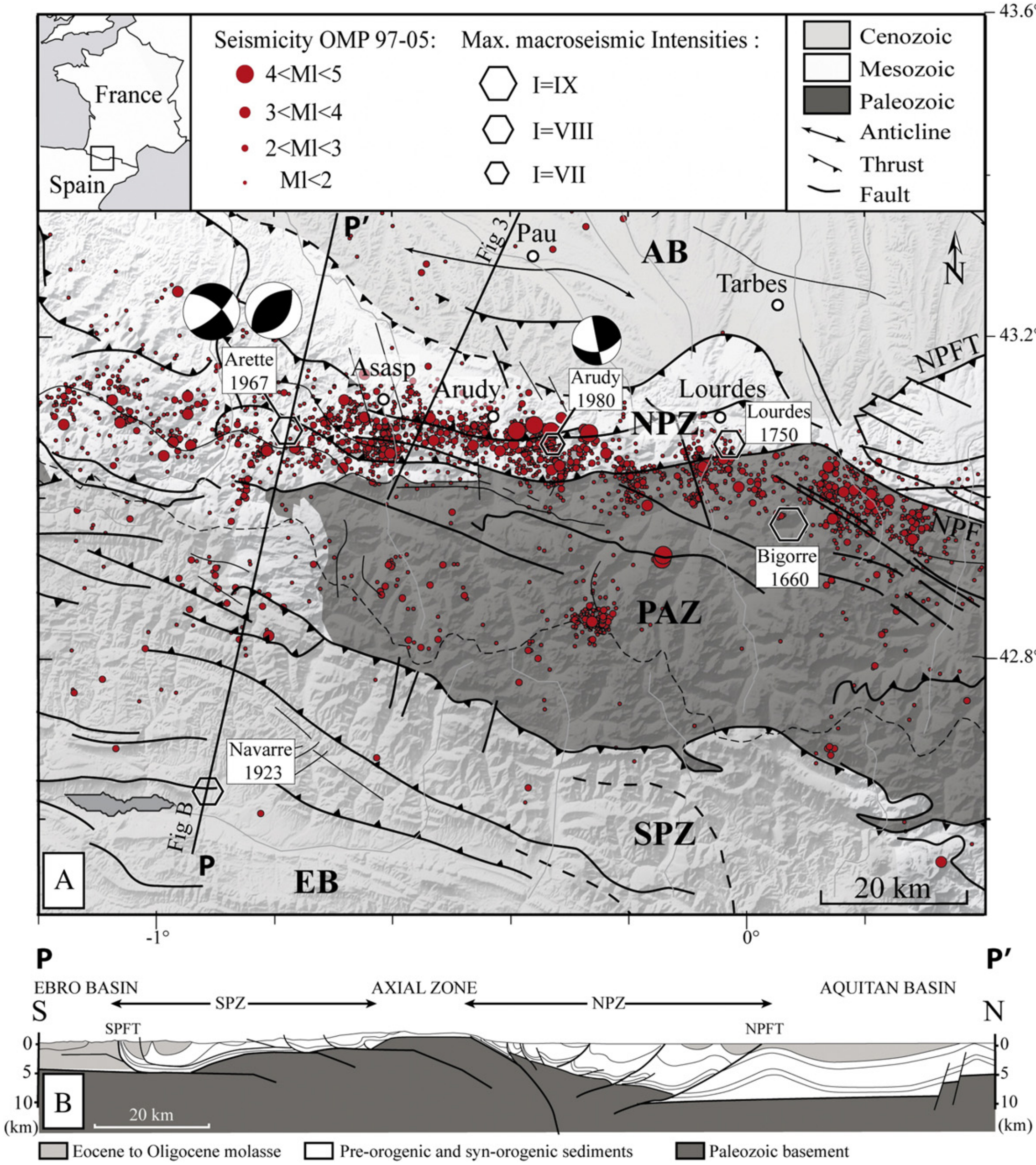

Fig. 1. (A) Structural map of the Western Pyrenees (modified after Barnolas and Chiron (1996)) with instrumental (dots) and historical (Hexagons) seismicity (source Observatoire Midi-Pyrénées). (B) Crustal cross-section of the west-central part of the range, simplified after Teixell (1998). Location in Figure 1A. AB: Aquitaine Basin, NPZ: North Pyrenean Zone, PAZ: Paleozoic Axial Zone, SPZ: South Pyrenean Zone, EB: Ebro Basin, NPFT: North Pyrenean Frontal Thrust, NPF: North Pyrenean Fault SPFT: South Pyrenean Frontal Thrust.

2. Regional tectonic setting and active faulting

2.1. Geological and morphological setting

The Pyrenees resulted from the collision between the Eurasian and Iberian plates since late Cretaceous to early Miocene time. They are aligned along a N110°E trend, and display a fan-like geometry in cross-section (Fig. 1B). The Paleozoic Axial Zone (PAZ) is bound by the North and South Pyrenean Zones (NPZ and SPZ), in which the Mesozoic and Cenozoic units overthrust the Tertiary infill of the Aquitaine and Ebro foreland basins. The North Pyrenean Fault (NPF) limits the PAZ from the NPZ. In the western part of the NPZ outcrops the remnants of the Mesozoic margin of the Iberian plate (e.g. Mattauer, 1990). The North and South Pyrenean Frontal Thrusts (NPFT and SPFT) separate the North and South Pyrenean Zones from their foreland basins.

This fan-like geometry resulted from a polyphased evolution: an extensional episode, linked to the opening of the Bay of Biscay and of the North Atlantic (Latest Jurassic to Santonian times) gave way to a left-lateral transtension episode (Olivet, 1996). The whole displacement is not well constrained and ranges from one to several hundred kilometers (Grandjean, 1994; Le Pichon et al., 1971; Olivet, 1996; Roest and Srivastava, 1991; Sibuet and Collette, 1991; Sibuet et al., 2004; Srivastava et al., 1990). Collision propagated from east to west during the Paleogene (Beaumont et al., 2000; Choukroune, 1976; Muñoz, 1992; Roure et al., 1989; Teixell, 1998). This resulted in a more intensive shortening to the east (90–165 km; Beaumont et al., 2000; Mattauer, 1990; Muñoz, 1992; Roure et al., 1989; Vergés, 1994; Vergés et al., 1995) than to the west (70–80 km; Grandjean, 1992; Teixell, 1996). Deformation reached its highest intensity during Eocene to Oligocene times (e.g. Fitzgerald et al., 1999; Pujalte et al., 2002; Vergés et al., 1995)