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Cenozoic right-lateral wrench tectonics in the Western Pyrenees (Spain): The Ubierna Fault System

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ABSTRACT

A study of macro and mesostructural deformation patterns of the southern margin of the Cantabrian area (Western Pyrenees, Spain) has revealed a complex Cenozoic tectonic framework. Right-lateral tectonics reactivated inherited WNW–ESE striking faults, which developed during Late Paleozoic and Early Triassic events, and Late Jurassic to Early Cretaceous main rifting stage. The Ubierna Fault represents the southern boundary of the Mesozoic basin. During the Oligocene (even Eocene) to present day deformation, this fault and the Ventaniella Fault located to the south in the study area acted as right-lateral slightly transpressive elements forming a 120 km long and 15 km wide overstep area, here named Ubierna Fault System, where the cumulative right-lateral displacement exceeds 15 km.

The Cenozoic tectonic framework of the Ubierna Fault System includes reactivation along the WNW–ESE faults, development of negative and, mostly, positive flower structures, branch faults, strike-slip duplexes, and releasing and restraining bends. NE–SW to ENE–WSW striking reverse faults and contractional horsetail terminations, and NNW–SSE striking normal faults and joints are produced by the WNW–ESE right-lateral strike-slip motion. The extensional elements are well developed and deformation progression implied their incorporation in the strike-slip system as right-lateral faults (forming part of strike-slip duplexes). The abundance of flower structures striking WNW–ESE and paralleling the main strike-slip faults, together with the overall uplift of the overstep area, testifies for a slight compressional component.

At a regional scale, the Ubierna Fault System represents the most prominent element of a Cenozoic transpressional belt, which incorporates the western portion of the Basque-Cantabrian Basin and the Asturian Massif area. Lateral transition between this transpressive belt and the dip-slip belt located to the east, occurs across an area experiencing along strike-shortening, which developed to accommodate the eastward extrusion of the transpressional belt.

1. Introduction

The Basque-Cantabrian and Asturian Massif areas represent the western portion of the Pyrenean Belt, bounded to the south by the Duero Foreland Basin (Fig. 1). They shared with the other portions of the Iberia–Eurasia boundary a multiphase Meso-Cenozoic deformational history. A Triassic extensional stage predated the main Upper Jurassic to Lower Cretaceous extensional to left-lateral transtensional phase associated with the opening of the North Atlantic margin and the Bay of Biscay (e.g. Le Pichon and Sibuet, 1971; Muñoz, 2002; Olivet, 1996; Roest and Srivastava, 1991). Uncertainties exist about the Mesozoic rifting stage, which was constrained by magnetic anomalies of unclear origin. In fact, it has been recently recognised that many anomalies used in previous plate tectonic reconstructions are not associated with sea-floor spreading, but were caused by serpentinisation during mantle exhumation (Sibuet et al., 2007). During the Upper Cretaceous relative motion of the Eurasian and Iberian plates changed from divergent to convergent leading to the inversion of previously developed basins (e.g. Muñoz, 1992; Vergés et al., 2002). In the study area such an inversion was oblique involving a mainly WNW–ESE striking normal fault system (e.g. Barnolas and Pujalte, 2004; García-Mondéjar, 1996; Soto et al., 2007) with an overall N–S shortening direction (e.g. Muñoz, 2002). In greater detail, magnetic anomalies distribution in the North Atlantic and in the Bay of Biscay indicates the existence of three convergence stages (e.g. Rosenbaum et al., 2002 and references therein): an Upper Cretaceous left-lateral oblique convergence followed by Paleocene–Eocene right-lateral wrench tectonics, with an associated displacement of about 60 km (e.g. Roest and Srivastava, 1991) and an Oligocene to Miocene right-lateral oblique convergence. In the offshore portion of the belt many right-lateral WNW–ESE striking faults are interpreted as reactivated faults (e.g. Boillot and Malod, 1988; Lepvrier and Martínez-García, 1990). In the onshore portion, the Ubierna Fault System could represent the south-eastern segment of an about 300 km-long right-lateral strike-slip shear zone (Ventaniella-Ubierna Faults System; e.g.

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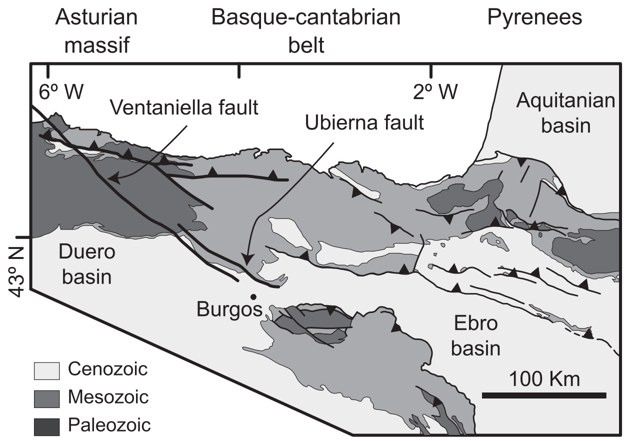

Fig. 1. Geological map of the northern Iberia margin.

Boillot and Malod, 1988; De Vicente et al., 2011) (Fig. 1). However, amount of displacement, timing and relationships between strike-slip and dip-slip movements are still under debate and, although the presence of right-lateral directional movements along the Ubierna Fault System is documented (e.g. Hernaiz, 1994), they are considered as subordinated features within a mostly compressional framework (e.g. Alonso et al., 1996; Espina et al., 1996).

In this work we present new mesostructural data from the Ubierna Fault System and surrounding area. These data provide important insights on the kinematic of the corresponding fault system (e.g. Keller et al., 1995; Kim et al., 2004). However, the complex structural assemblage observed in strike-slip fault systems (e.g. Harding, 1974; Sylvester, 1988; Woodcock and Schubert, 1994), implies that they cannot be directly upscaled (e.g. Storti et al., 2006) due to the presence of “local” patterns associated with second order structures (i.e. branch faults, flowers structures etc.). For this reason we present and discuss meso-scale features and sites of particular interest, which allow to fully constrain the kinematic of this fault system.

The entire area is re-interpreted as a wide right-lateral shear zone (Fig. 2), mostly reactivating an inherited extensional fault system, which includes a large range of structures associated with wrench tectonics: positive flowers, branch faults, restraining bends, antithetic faults, pull-apart basins with associated diapirs, strike-slip duplexes (e.g. Aydin and Nur, 1982; Cunningham and Mann, 2007; Dewey et al., 1998; Dooley and McClay, 1997; Harding, 1974; Riedel, 1929; Sanderson and Marchini, 1984; Storti et al., 2003; Sylvester, 1988; Wilcox et al., 1973; Woodcock and Fischer, 1986; among others).

2. Geological setting

The Ubierna Fault System is an WNW–ESE elongated highly deformed overstep area between the Ubierna and the Ventaniella faults (Fig. 2). It divides the Upper Jurassic to Lower Cretaceous

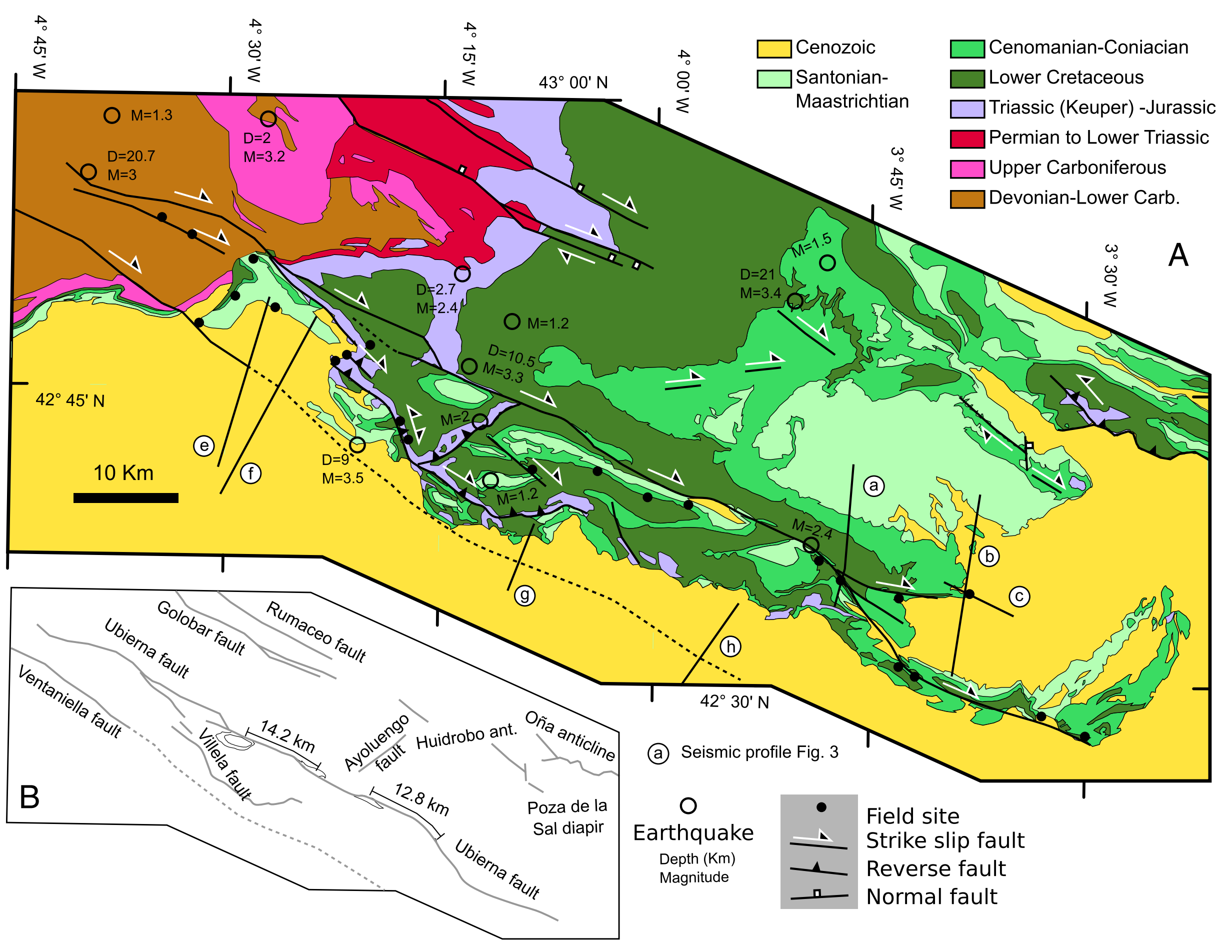

Fig. 2. (A) Geological map of the study area with traces of seismic sections in Fig. 3, earthquakes location and field sites location. Earthquakes data are from data from the MDD network (Instituto Geográfico Nacional, Madrid). (B) Scheme of the major fault systems and position of the markers used to compute the displacement along the Ubierna Fault PDZ. In the following figures this scheme will be used to indicate the position of an area of interest or field site. Map in (A) is modified from: Del Olmo and Ramírez del Pozo (1972); Carreras Suárez et al. (1978); Portero García et al. (1978); Colmenero et al. (1982); Ambrose et al. (1984); Lobato et al. (1985); Olivé Davó et al. (1990); López Olmedo et al. (1997a,b); Pineda Velasco and Martín Serrano (1997a); Pineda Velasco and Martín Serrano (1997b); Pineda Velasco et al. (1997).