Tectonophysics 632 (2014) 167–187

Contents lists available at ScienceDirect

Tectonophysics

journal homepage: www.elsevier.com/locate/tecto

Spatial and temporal variation of palaeoseismic activity at an intraplate, historically quiescent structure: The Concud fault (Iberian Chain, Spain)

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ARTICLE INFO

Article history:
Received 14 March 2013
Received in revised form 14 May 2014
Accepted 10 June 2014
Available online 20 June 2014

Keywords:
Active fault
Palaeoseismic event
Coseismic displacement
Slip rate variation

ABSTRACT

Several faults in the Teruel and Jiloca grabens (Iberian Chain, NE Spain), particularly the targeted Concud fault, show evidences of recent, continuous activity, despite their scarce instrumental and historic seismic record.
Three trenches are studied in two locations (central and southeastern sectors of the Concud fault, respectively). After comparing with previous works, we reconstruct a palaeoseismic succession with nine events distributed along a maximum time lapse bracketed between 81.6 and 14.0 ka. This succession involves an average recurrence interval of 7.4 ± 2.8 ka, with individual interseismic periods between 4 and 11 ka. The calculated coseismic displacements range from 0.6 to 2.7 m, with an average value of 1.9 m that results in a slip rate of 0.26 mm/a. Due to the incomplete sedimentary record for Holocene times, we cannot affirm that the youngest event detected was actually the last one. We conjecture that some other events may have occurred during the period between 15.0 and 3.4 ka.
Temporal and spatial variations have been detected in palaeoseismic activity, specifically in the distribution of coseismic displacements. First, a non-steady slip rate is evidenced during Plio-Pleistocene times: a long-term tendency towards increasing slip rate is modulated in detail by the occurrence of minor cycles, as the sequence of increasing/decreasing activity recorded within the studied time window suggests. Secondly, an asymmetric distribution of coseismic slip along the fault trace is observed, paralleling the distribution of total fault throw, which shows an absolute maximum close to the southeastern tip. A combination of factors is proposed to explain this: branching of the main fault; dominant, remote-stress-driven slip towards N 220° E on the NW–SE fault segment; guided movement on the passive, NNW–SSE segment giving rise to an oblique roll-over monocline; and decoupling of the hanging-wall block owing to the transverse Los Mansuetos–Valdecebro fault zone.

1. Introduction

At active plate boundaries, where fault slip rates are high, recurrence periods of large earthquakes (magnitude of 6 and above) are relatively short, so that historical or even instrumental records can include a number of them. In contrast, the seismic record of most intraplate areas covers a period shorter than the average recurrence interval of large earthquakes (usually in the order of thousands of years; Johnston and Kanter, 1990; Liu and Zoback, 1997), therefore it may not contain any evidence of catastrophic events. The globally averaged energy release within intraplate areas is almost negligible compared to that produced by earthquakes associated with plate boundaries (Johnston and Kanter, 1990), which results in longer recurrence periods but not necessarily in less intense events. Regions without previous historical record of seismicity have experienced destructive shakes; the New Madrid (Missouri) sequence of 1811–1812 (Mw = 7.5–8.3; Liu and Zoback, 1997), and the Tennant Creek (Australia) event in 1988 (Ms = 6.3–6.7; Crone et al., 1992) are prime, classical examples.

Although hazard maps are used in many countries to provide a foundation for earthquake preparation and mitigation policies, they often fail to predict what actually happens (Stein et al., 2012). The 2008 Wenchuan, 2010 Haiti, and 2011 Tohoku earthquakes were highly destructive seisms that occurred in areas mapped as relatively safe (Stein et al., 2012). Often crucial data needed for the elaboration of hazard maps are lacking, incomplete, or misinterpreted. As a result, this task is a challenge even in areas where there are good earthquake records from instrumental seismology (typically active plate boundaries). The challenge is even greater in most other areas, where far less data are available because instrumental and historic records are too short compared to the long recurrence time of large earthquakes (Stein et al., 2012). Assessment of earthquake hazard based on such limited historic record may be biased towards overestimating the hazard in regions of recent large earthquakes and underestimating the hazard where seismicity has been low during the historic record (Li et al., 2009).

Understanding the seismic behavior of active faults, and hence assessing seismic hazard, will therefore heavily rely on widening the

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http://dx.doi.org/10.1016/j.tecto.2014.06.012
0040-1951/© 2014 Published by Elsevier B.V.

temporal perspective of seismic activity. This is addressed by identifying and dating ancient earthquakes by means of palaeoseismological studies on trenches crossing such faults (Allen, 1986; McCalpin, 1996; Yeats et al., 1997). Nonetheless, upgrading palaeoseismic results beyond a mere phenomenological description requires focusing on the relationships between earthquake mechanisms and structural framework (Talwani, 1999; Yeats et al., 1997). It is known that size, orientation and segmentation of active faults control the occurrence and magnitude of seismic events (DePolo et al., 1991; McCalpin, 1996; Talwani, 1999). Visible offset of stratigraphic or geomorphologic markers allows us to evaluate average slip rates. But, beyond these basic structural parameters, a detailed knowledge of geometry, kinematics and dynamics of seismogenic faults becomes necessary in order to adequately understand the palaeoseismic record. This is especially true when a significant volume of palaeoseismological information is available from a given fault. Spatial and temporal distribution of palaeoseismic activity, in particular, variations of coseismic displacements, will be probably detected. These should be interpreted in the light of kinematical and dynamical models concerning either the whole faults or local anomalies related to inhomogeneities of stress fields or secondary accommodation structures (McCalpin, 1996).

The Iberian Chain, an intraplate range in eastern Spain (Fig. 1a), shows moderate to low instrumental and historic seismicity (Fig. 2), which has led us to classify the study area as safe in the official hazard map of Spain (Fig. 1b). However, this region contains a number of active, geologically well documented faults moving since Pliocene times (Fig. 1c) (Gutiérrez et al., 2012; Simón et al., 2012). Faults showing the most conclusive evidences of recent, continuous activity are linked to the intra-mountain Teruel–Jiloca graben system (Fig. 1d). In particular, the Concud fault (southern sector of the Jiloca graben) has been the object of preliminary palaeoseismological characterization (Simón et al., 2005), morphotectonic analysis (Lafuente et al., 2011c), as well as trench studies at an exceptional outcrop near its southeastern tip (Gutiérrez et al., 2008; Lafuente et al., 2011a). The results allowed classifying it as a moderately active fault during Middle to Late Pleistocene times, although no historical destructive earthquake is associated to it. This paper presents the results obtained at three additional trenches in two separate locations (central part of the trace and southeastern tip). After comparing and synthesizing all the available results, we have detected some spatial and temporal variations in the palaeoseismic record, and specifically in the distribution of coseismic displacements. These issues will be addressed on the basis of a detailed characterization of geometry, kinematics and dynamics of the Concud fault.

2. Geological setting

The Iberian Chain, located within the Iberian Plate, underwent multiple compressions during the Alpine Orogeny (Liesa and Simón, 2009). The eastern sector shows a number of Neogene–Quaternary extensional basins that postdate the Alpine compressional structures and represent the onshore deformation of the Valencia Trough (Roca and Guimerà, 1992; Simón, 1984) (Fig. 1a, c). Two distinct rift episodes can be distinguished (Simón, 1983, 1984): the first one (Miocene) produced the main NNE–SSW trending grabens (Teruel and Maestrazgo); the second one (Late Pliocene–Quaternary) gave rise to the NNW–SSE

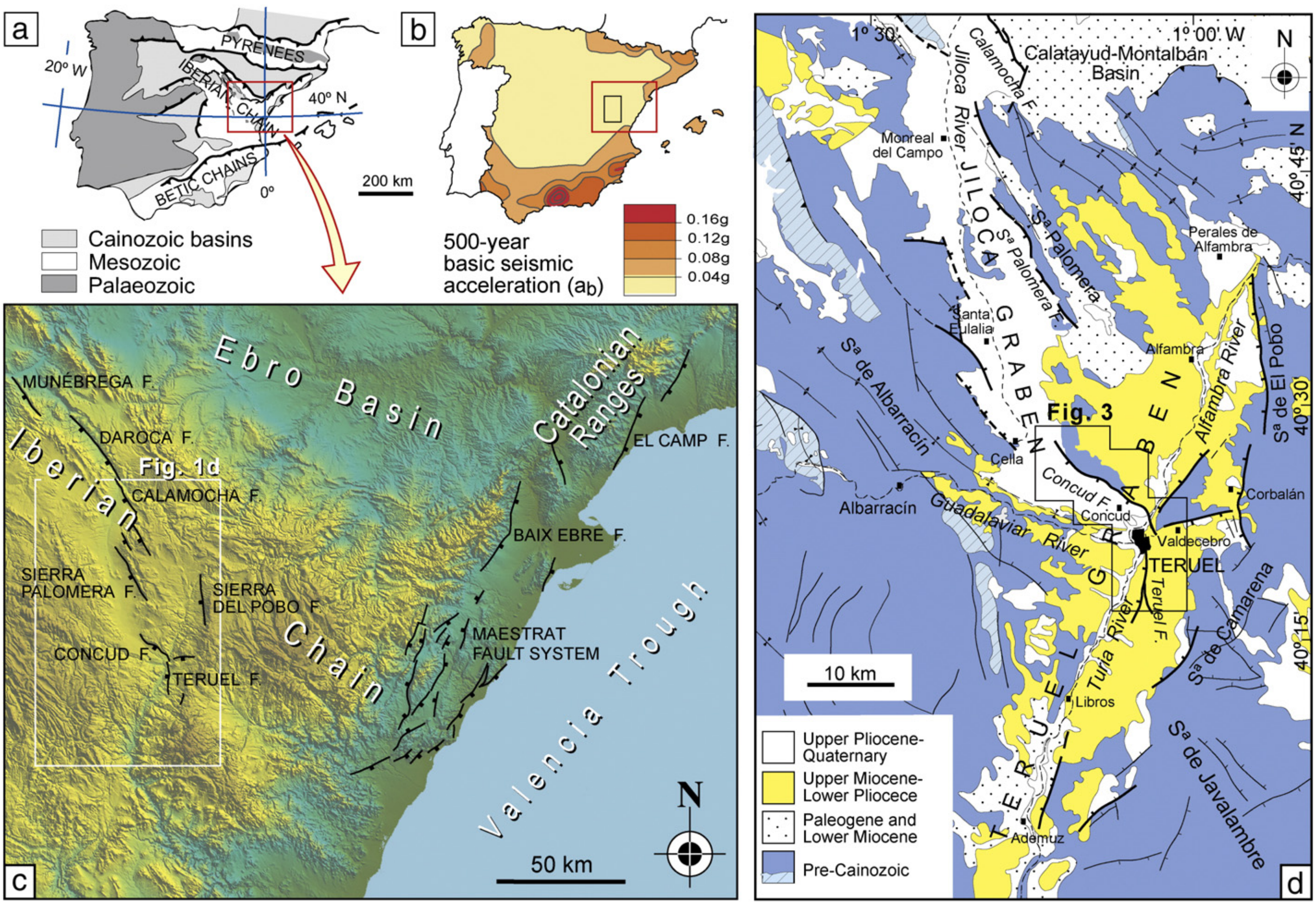

Fig. 1. (a) Location within the Iberian Peninsula. (b) Seismic hazard map of Spain established by the official regulation for earthquake safety building policy (Ministerio de Fomento, 2002). (c) Digital Elevation Model showing the main active faults within the central-eastern Iberian Chain and southern Catalonian Ranges. (d) Geological sketch of the Teruel and Jiloca grabens, with location of the Concud fault.