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Seismites from a well core of palustrine deposits as a tool for reconstructing the palaeoseismic history of a fault

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ABSTRACT

The Concud Fault is located at the junction between the Jiloca and Teruel grabens (central-eastern Iberian Chain, Spain). The Late Pleistocene activity of this fault has been well logged from structural and palaeoseismological trench studies, but only scattered data of the Late Pliocene seismic activity exist. The Late Pliocene–Early Pleistocene syn-tectonic infill consists of an endorheic continental succession in which a 75 m-long continuous well was drilled near the Concud Fault. Along the entire well core, several types of soft-sediment deformation structures with variable morphology, size and frequency have occurred including clastic dykes, load structures and slumps. The rigorous analysis of the deformation structures, their relationships with the involved sedimentary facies, and the discrimination of possible deformation mechanisms and trigger processes allow us to interpret part of them as seismically-induced structures. The recognition of 21 deformed beds (seismites) allow the Late Pliocene–Early Pleistocene seismic history of the Concud Fault to be reconstructed. Therefore, 21 seismic events (with $M \geq 5$) and an apparent recurrence period of about 45 ka have been inferred.

1. Introduction

Palaeoseismology analyzes evidence of palaeoearthquakes in the geologic record, most of them unknown from historical seismicity or instrumental data. Secondary palaeoseismic indicators (seismites, sensu Seilacher, 1969) refer to hard-rock and soft-sediment beds containing different kinds of deformation structures produced by earthquake-induced shock waves (McCalpin, 1996). Their study allows us to extend the seismic database backwards in the past, which is a critical issue in areas where the historic seismic record is short with respect to the average recurrence period of large earthquakes (Obermeier et al., 1990). This approach is especially important in seismic hazard analysis at sites of nuclear power plants, dams, waste repositories, and other critical structures (Mörner, 1989).

Seismites have been recognized in many depositional environments and sedimentary successions of different ages (see a recent review in Moretti and Van Loon, 2014). The lacustrine environments seem to be the most favorable for their occurrence (Alfaro et al., 1997; Alfaro et al., 2010; Alsop and Marco, 2011; Anand and Jain, 1987; Bowman et al., 2004; Koç Taşgın, 2011; Scott and Price, 1988; Van Loon et al., 1995). From the pioneer paper by Sims (1973), which reasonably correlated the occurrence of certain soft-sediment deformation structures (SSDSs) with recorded seismic events, many works have been devoted to this topic. Most of them describe deformed beds (load structures, clastic dykes, sand blows, etc.) in lacustrine successions of different ages cropping out in tectonically-active basins (Alfaro et al., 1999; Alsop and Marco, 2013; Ben-Menahem, 1976; Calvo et al., 1998; Davenport and Ringrose, 1987; El-Isa and Mustafa, 1986; Gibert et al., 2005; Hempton and Dewey, 1983; Hesse and Reading, 1978; Karlin and Abella, 1992; Moretti and Ronchi, 2011; Moretti and Sabato, 2007; Ringrose, 1989a, b; Rodríguez-Pascua et al., 2000; Weidlich and Bernecker, 2004).

Palaeoseismicity studies carried out in Holocene lacustrine basins are commonly based on the interpretation of high-resolution seismic reflection profiles, sedimentological analyses carried out on cores and well logs. In such cases, palaeoearthquake effects have not been recognized as SSDSs but from resedimentation events like homogenites, seismoturbidites or slides (Arnaud et al., 2002; Bertrand et al., 2008; Carrillo et al., 2008; Doig, 1986, 1990; Faridfathi and Ergin, 2012; Goldfinger, 2009; Leroy et al., 2010; Migowski et al., 2004; Shilts and Clague, 1992; Wagner et al., 2008). In this situation, it can be difficult to distinguish the influence of climate and tectonic activity on both the sedimentation rate and re-suspension processes (De Batist and Chapron, 2008). Nice examples of ancient seismically-induced SSDSs in well cores have been described by El Taki and Pratt (2012) and He et al. (2014). The scarcity of literature on soft-sediment deformation structures in well cores with a palaeoseismic perspective is difficult to explain since, generally, the continuous cores show a good preservation of the delicate primary lamination and bedding, soft-sediment deformation structures and trace fossils, especially in fine-grained deposits (Alfaro et al., 1995; Weimer and Tillman, 1980).

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In this paper, we analyze a core drilled in a 75-m thick succession of palustrine–lacustrine deposits of the southern Jiloca Basin (NE Spain), close to the Concud Fault. Most of this succession corresponds to syntectonic deposits, dated from palaeontological and magnetostratigraphic data as Late Pliocene–Pleistocene (Ruscinian-Villafranchian; Alcalá et al., 2000; Godoy et al., 1983a,b; Moissenet, 1982; Opdyke et al., 1997). The recent tectonic activity and palaeoseismicity of this fault are well known from several works (e.g. Lafuente, 2011; Lafuente et al., 2011a, 2014; Moissenet, 1985; Simón, 1983; Simón et al., 2005).

Our objectives are: (i) to describe the SSDSs that occur at various stratigraphic levels within the well core; (ii) to suggest general criteria to recognize seismites in well cores; (iii) to distinguish seismically from non-seismically induced SSDSs; and (iv) to interpret the vertical frequency of seismites in terms of approximate recurrence period for medium- to high-magnitude seismic events in this area.

2. Geological setting

The central-eastern sector of the Iberian Chain (eastern Spain) displays a large network of extensional basins that represent the onshore deformation of the Valencia Trough since Neogene times (Álvaro et al., 1979; Roca and Guimerà, 1992; Simón, 1982, 1989; Vegas et al., 1979) (Fig. 1). Basins are controlled by normal faults with two main orientations, NNE–SSW and NNW–SSE. These faults mainly represent the reactivation of structures inherited from the Late Variscan strike-slip tectonics, the Mesozoic rift episode or the Palaeogene–Early Neogene compressional tectonics (e.g. Álvaro et al., 1979; Capote et al., 2002; Salas and Casas, 1993). Since the Neogene, the extensional deformation has propagated westwards from the Mediterranean Sea (where sedimentary infilling started by the Early Miocene), to the Maestrat (Early–Middle Miocene), Teruel (Middle–Late Miocene) and Jiloca (Late Pliocene) grabens (Capote et al., 2002). They evolved through two distinct rift episodes (Simón, 1982, 1983): the first one, produced the main NNE–SSW trending grabens (Teruel and Maestrat) during the Miocene, and the second one gave rise to the NNW–SSE trending Jiloca graben and reactivated the Teruel and Maestrat grabens in the Late Pliocene–Quaternary. These structures developed under a regional stress field that has been characterized as an almost radial tension (σ_1 vertical, $\sigma_2 \approx \sigma_3$) with trajectories of the minimum stress axis σ_3 mainly trending ENE–WSW (Arlegui et al., 2005; Simón, 1989).

Our study area is located at the junction of the Jiloca and Teruel Basins (Fig. 1 and 2a). The northern sector of the Teruel Basin is a half-graben controlled, at its eastern boundary, by large N–S striking fault systems located at the Sierra del Pobo and Javalambre mountain fronts (Liesa, 2011; Moissenet, 1983; Simón, 1983). The basin is filled with Neogene red clastic distal alluvial fan deposits that grade basinwards into lacustrine carbonates and evaporites with an estimated total thickness of up to 500 m (Moissenet, 1980). These deposits lie unconformably on, or in tectonic contact with, Mesozoic–Oligocene rocks (Ezquerro et al., 2012a; Godoy et al., 1983a,b; Moissenet, 1983; Weerd, 1976).

The sedimentary fill of the northern Teruel Basin was divided by Weerd (1976) into four formal lithostratigraphic units: the Peral Fm. comprises red terrigenous facies; the Alfambra Fm. includes white carbonates with interbedded clays, coal and gypsum; the Tortajada Fm. consists of white gypsums with interbedded carbonates; and the Escorihuela Fm. is formed by rusty brown sands and clays with lignites, and white limestones. Godoy et al. (1983a,b) established five informal units that represent alternating red clastic facies (Lower Detrital Unit-Rojo 1, Rojo 2 and Rojo 3 units) and carbonate deposits (Páramo 1 and Páramo 2 units). The two carbonate units, and locally the Rojo 2 units, grade laterally into evaporite facies. Strong interfingering of the formal units in the central and southern sectors of the basin (out of the northern area where they were defined) produce several vertical facies changes. The informal units are based on such vertical changes and subdivide the formal ones, permitting a better constraining of the lithostratigraphy. These informal units have been traditionally used for regional description of the lithostratigraphy and have been adopted for national geological maps (e.g. Godoy et al., 1983a,b). The Peral Fm. includes Rojo 1 and Rojo 2; the Alfambra Fm. includes Páramo 1 and Páramo 2; the

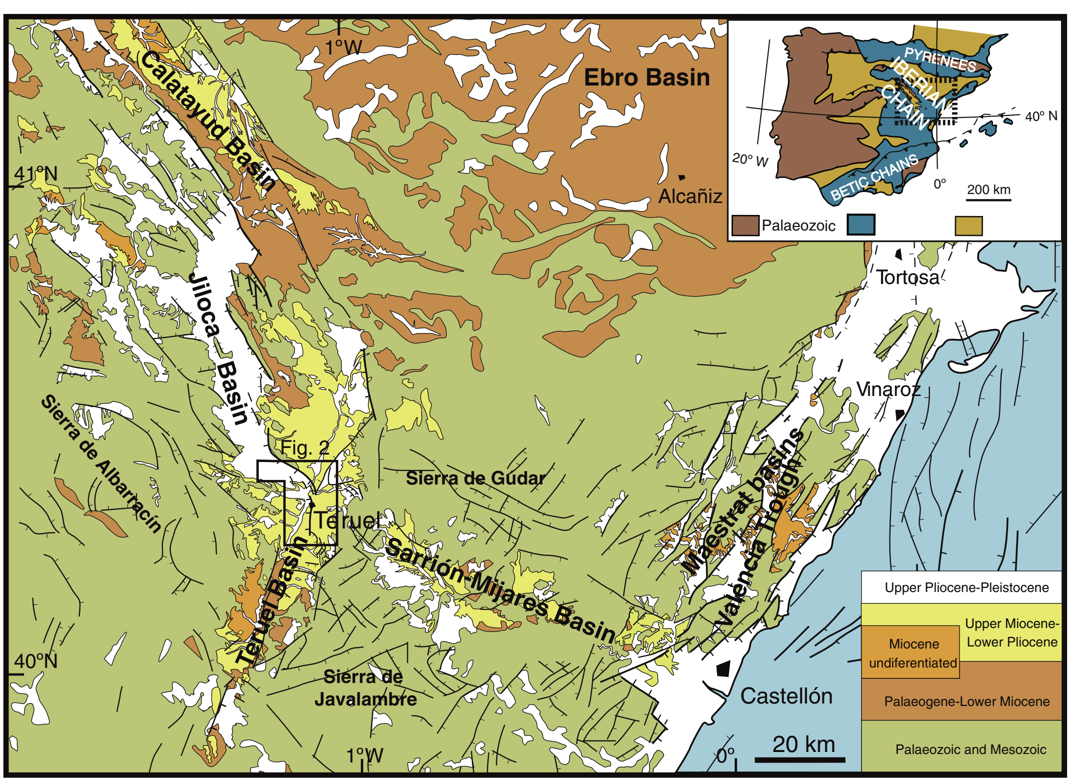

Fig. 1. Neogene–Quaternary extensional basins and main active faults in the central-eastern Iberian Chain. Inset: location of the study area within the Iberian Peninsula.