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New evidence of recent fracturing at the relay zone between the Concud and Teruel faults (eastern Iberian Chain)

Nuevas evidencias de fracturación reciente en la zona de relevo entre las fallas de Concud y Teruel (Cordillera Ibérica oriental)

Alba Peiro, José L. Simón and Carlos L. Liesa

Departamento de Ciencias de la Tierra, Facultad de Ciencias, Universidad de Zaragoza. C/ Pedro Cerbuna 12, 50009 Zaragoza, España.
albapeirch@gmail.com, jsimon@unizar.es, carluis@unizar.es

ABSTRACT

The NW-SE to NNW-SSE striking Concud Fault and the N-S striking Teruel Fault are extensional structures showing a right relay arrangement. The hectometre-scale offset produced by both structures in the Neogene materials of the Teruel basin is transferred to each other by means of a relay ramp dipping towards NNW. In this study we present new information on recent (Late Pleistocene) brittle deformation structures, some of them located within the relay zone and others aligned with the northwards prolongation of the Teruel Fault. The observed faults and fractures are mostly parallel to the major faults (NNW-SSE), while signs of transverse structures (pointing to hard linkage) are negligible. The Concud and Teruel faults are independent structures from the geometrical and kinematical point of view, but we interpret that there is a mechanical interaction between them, a previous stage to linkage by hypothetical future northwards propagation of the Teruel fault.

Key-words: *Normal fault, relay ramp, mechanical interaction, Late Pleistocene.*

RESUMEN

La Falla de Concud (NW-SE a NNW-SSE) y la Falla de Teruel (N-S) son fallas extensionales dispuestas en relevo diestro. El salto de escala hectométrica que ambas estructuras producen en los materiales neógenos de la fosa de Teruel se transfiere de una a otra mediante una rampa de relevo con pendiente hacia el NNW. En este trabajo se presenta nueva información sobre estructuras frágiles recientes (Pleistoceno Superior), algunas localizadas dentro de la zona de relevo y otras alineadas con la prolongación septentrional de la falla de Teruel. Las fallas y fracturas observadas son en su mayoría paralelas a las fallas mayores (NNW-SSE), mientras que los indicios de estructuras transversales (que podrían apuntar a una 'conexión dura' entre las fallas de Concud y Teruel) son muy escasos. Ambas fallas son independientes desde el punto de vista geométrico y cinemático, pero interpretamos que interactúan mecánicamente, en un estadio previo a la coalescencia por una hipotética futura propagación hacia el norte de la falla de Teruel.

Palabras clave: *Falla normal, rampa de relevo, interacción mecánica, Pleistoceno Superior.*

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Introduction

The Neogene-Quaternary extensional basins of the eastern Iberian Chain represent the onshore deformation linked to rifting of the Valencia Trough. The largest one among them is the Teruel Basin, in which the active, right-relay arranged Concud and Teruel faults are two of the main active structures (Fig. 1).

Lafuente *et al*. (2011) have shown that both faults are independent from the geometrical and kinematical point of view, as evinced by their distinct transport directions (N275ºE and N220ºE, respectively). Nevertheless, these authors postulate a certain mechanical interaction between them, and hypothesized that they are in a transient stage previous to linkage. Two different alternative models of fault linkage (either present or future) through the relay zone were considered in that work:

a) One or several transfer faults cutting transversely the relay zone (*hard linkage*, in the sense of Gibbs, 1984), which could be parallel to the nearby Los Mansuetos-Valdecebro E-W striking fault zone.

b) Northwards prolongation of the main trace of the Teruel Fault up to abut the NW-SE trending trace of the Concud Fault.

The purpose of the present study is to present new evidence about recent brittle deformation (meso-scale faults and fractures) at this relay zone, and to analyse the geometry, kinematics and dynamics of such structures in order to test both linking hypotheses.

Geological setting

The Neogene-Quaternary Teruel and Jiloca grabens are located in the central-eastern Iberian Chain (Fig. 1). The NNW-SSE trending Jiloca Graben results from right-relay arrangement of three important normal faults; one of them is the Concud Fault, which bounds its southern sector. The NNE-SSW trending Teruel Graben is mainly controlled by nearly N-S striking faults. At the junction of both extensional basins, the

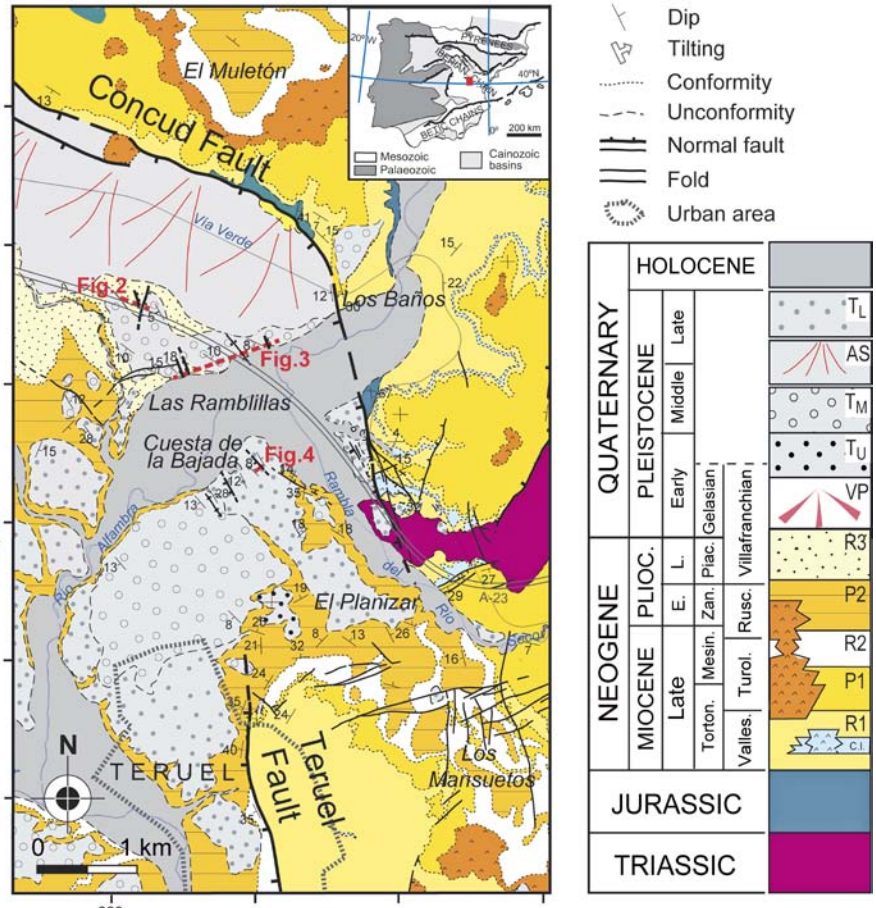

Fig. 1.- Location and geological map of the relay zone between the Concud and Teruel faults (modified from Lafuente, 2011). Cross sections studied at the Autovía Mudejar (Fig. 2), Las Ramblillas (Fig. 3) and northeastern Cuesta de la Bajada (Fig. 4) are also located. R1, R2, R3: Rojo 1, Rojo 2 and Rojo 3 units; P1, P2: Páramo 1 and Páramo 2; VP: Villafranchian pediment; TU, TM, TL: Upper, Middle and Lower terraces; AS: Pleistocene alluvial system. Color figure in the web.

Fig. 1.- Situación y mapa geológico de la zona de relevo entre las fallas de Concud y Teruel (modificada de Lafuente, 2011). . Se localizan asimismo las secciones estudiadas en la Autovía Mudéjar (Fig. 2), Las Ramblillas (Fig. 3) y el sector noreste de Cuesta de la Bajada (Fig. 4). R1, R2, R3: unidades Rojo 1, Rojo 2 y Rojo 3; P1, P2: Páramo 1 y Páramo 2; VP: glacis villafranquiense; TU, TM, TL: terrazas Superior, Media e Inferior; AS: sistema aluvial pleistoceno. Figura en color en la web.

Concud and Teruel faults, together with the transversal Los Mansuetos-Valdecebro fault zone, cut the Neogene filling of the graben.

In the surroundings of Teruel city, these Neogene deposits have been divided into several informal units (Godoy *et al.,* 1983): *Rojo 1* (red lutites with occasional conglomerates, sandstones, limestones and gypsum; Vallesian in age); *Páramo 1* (white lacustrine carbonates, Turolian); *Rojo 2* (red-orange lutites, Upper Turolian-Ruscinian); *Páramo 2* (white lacustrine carbonates, Ruscinian); and *Rojo 3* (red lutites, Ruscinian-Villafranchian). Conglomerates and lutites of a Villafranchian pediment overlie and are interbeded with the Rojo 3 unit.

Quaternary deposits include fluvial gravel, sand and silt belonging to several terrace levels (usually grouped into Lower, Middle and Upper terraces), as well as to an alluvial fan system sourced at the Concud mountain front. Numerical ages available in the area (mainly based on U/Th and optical luminescence, OSL) indicate that the Middle Terrace is Middle Pleistocene (250 ± 32 to 90.5 ± 5.3 ka) and the Lower Terrace is Late Pleistocene in age (22.0 ± 1.6 ka to 14.9 ± 1.0 ka) (Arlegui *et al*., 2005; Gutiérrez *et al*., 2008; Lafuente *et al*., 2008, 2014; Lafuente, 2011).

The Concud Fault is 14.2 km long, and shows a dominant NW-SE strike that veers to NNW-SSE at its southern segment. The Teruel Fault is 9.0 km long and strikes nearly N-S. Both faults produce hectometre-scale offset of Neogene materials of the Teruel basin: net slip of 255-290 and 270 m, respectively, measured at the youngest pretectonic marker, *i.e.* the top of the Páramo 2 unit (Lafuente *et al.,* 2011; Simón *et al*., 2017). Their shared hanging-wall block presents a gentle roll-over structure, with an average dip of the Páramo 2 beds close to 2º.

Displacement between the Concud and Teruel faults is transferred by a NNW-dipping relay ramp. Their displacement-length profiles (Lafuente *et al.,* 2011) show high displacement gradients near the relay zone, therefore involving sudden slip transference.

Recent faults at an outcrop scale

The relay zone between the Concud and Teruel faults is an area of 10 km^2 where several recent deformation structures can be observed and analysed. Three key sites have been studied: *Autovía Mudéjar, Las Ramblillas and Cuesta de la Bajada.*

Excavation of slopes for the A-23 highway (*Autovía Mudéjar*), some 2 km north of Teruel, allowed to observe several brittle structures deforming both the Middle Terrace and the *Rojo 3* unit (Fig. 2): a NNE-SSW striking fault zone, minor NNW-SSE striking faults, and numerous nearly vertical fractures. Faults are antithetic to the Teruel and Concud faults, and involve a composite, total throw of *ca.* 18 m affecting the bottom of the Middle Terrace gravels. Striae measured on fault surfaces indicate transport direction of the hanging-wall blocks towards ENE (Fig. 2C-E).

Along *Las Ramblillas* section (Fig. 3), three important faults affecting both Pleistocene and Villafranchian deposits are exposed. In its western sector, two NNW-SSE striking faults synthetic to the Concud Fault produce metric and decametric throws in the Middle Terrace deposits, dividing it into three tilted blocks (Fig. 3B). The most conspicuous fault has an average orientation N157ºE, 48ºW and transport direction towards WSW. Another fault cropping out to the east is antithetic to the Concud Fault and produces a throw of 3 m (Fig. 3C). Surface information, together with subsoil data provided by two drilling cores (one of them described by Ezquerro *et al.,* 2016) has allowed reconstruction of the cross section of Fig. 3A It has been noticed that the structure corresponds to a syncline whose core presents an anomalously high thickness of Middle Terrace deposits. This structure has been interpreted as the result of the movement of a blind fault, similar to the ones of the western sector and synthetic to the Concud Fault. This inferred structure would produce a displacement enough to provide accommodation space for syntectonic sedimentation.

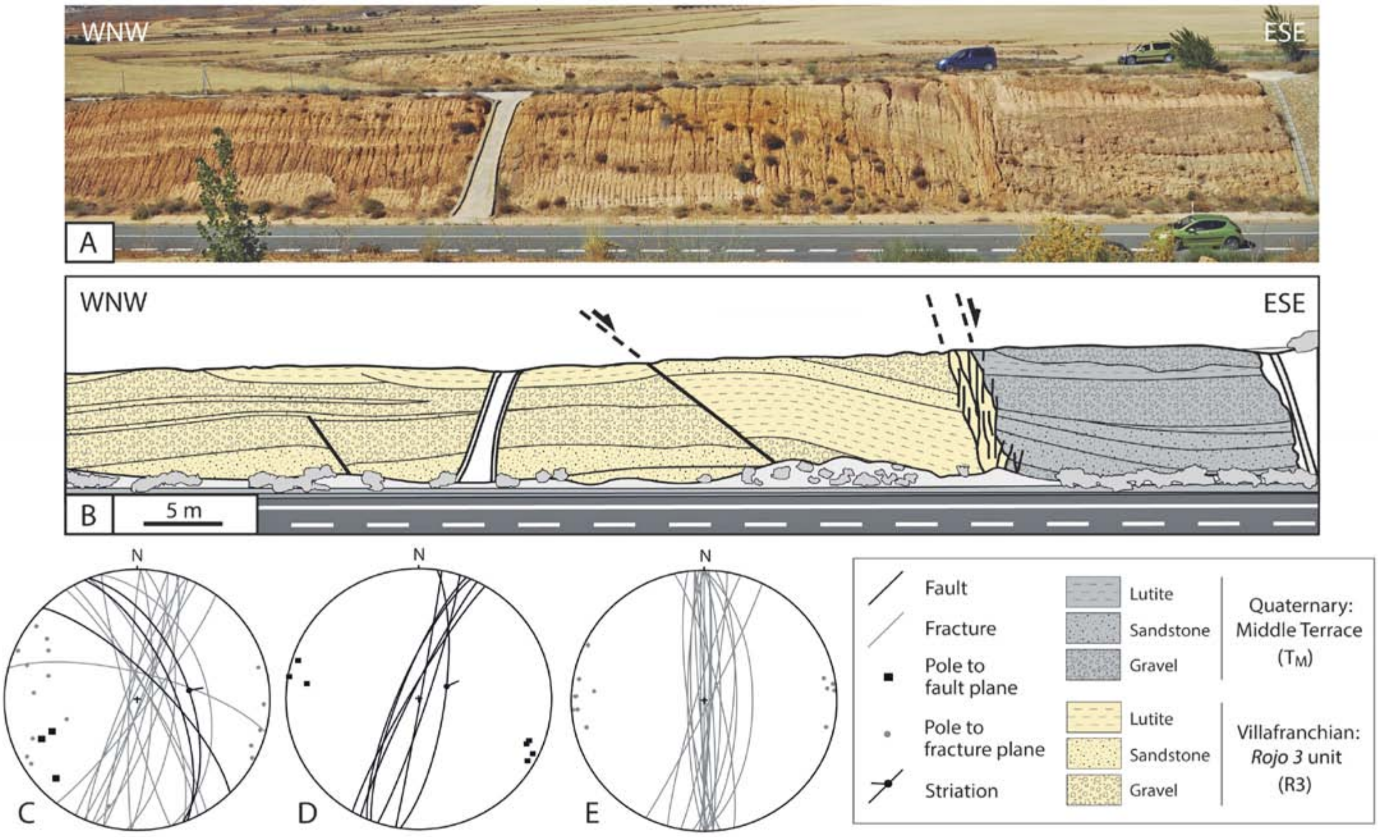

Fig. 2.- A) and B) Normal faults affecting both the Rojo 3 unit and the Middle Terrace deposits at slopes from the A-23 highway. C) Minor faults and fractures in the footwall block. D) Faults and fractures that constitute the main fault zone. (E) Fractures found in the hanging-wall block. Color figure in the web.

Fig. 2.- A) y B) Fallas normales afectando tanto a la unidad Rojo 3 como a los depósitos de la Terraza Media en los taludes de la autovía A-23. C) Fallas menores y fracturas en el bloque levantado. D) Fallas y fracturas que componen la zona de falla principal. E) Fracturas encontradas en el bloque hundido. Figura en color en la web.

At the northeastern sector of *Cuesta de la Bajada* site, Lower Terrace materials lie on top of the visible sedimentary succession. They are deformed by a main fault zone oriented N138ºE, 53ºW and other associated, both synthetic and antithetic minor extensional faults and fractures (Fig. 4). A throw of 2.4 m has been measured for the main fault zone, and a hectometre-scale length has been estimated based on the observation of its trace on another quarry slope located 60 m northwards from that represented in figure 4. The ensemble of brittle structures in this section can be interpreted as conjugate shear fractures. Therefore, although no striation has been observed on them, the orientation of the stress axes σ_1, σ_2, and σ_3 can be approached by applying the Anderson's model of faulting (Anderson, 1951, Fig. 4C).

Another significant fault affecting Middle Terrace deposits has been inferred at the southwestern sector of Cuesta de la Bajada site, with a minimum estimated throw of about 7 m. Our interpretation is based on differences in lithology and dip between two separate rock bodies; one of them exhibits bed tilting (up to 28º E) that is interpreted as a roll-over structure in the hanging-wall block.

Discussion and conclusions

The extensional faults and fractures observed in the three studied sites are mostly parallel, both synthetic and antithetic to the macrostructures. Together with their associated bends, they make a structural band clearly aligned with the northwards prolongation of the Teruel Fault. The available striation data indicate an ENE-WSW movement plane for them, which is consistent with the local stress

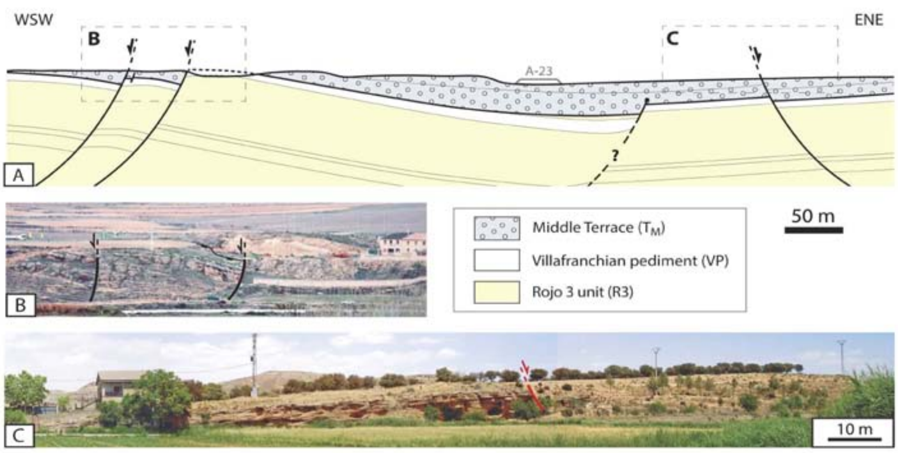

Fig. 3.- A) Cross section of Las Ramblillas site. B) and C) Pictures of the displacement and tilting of the Villafranchian and Quaternary caused by Las Ramblillas faults. Color figure in the web.

Fig. 3.- A) Corte geológico del afloramiento de Las Ramblillas. B) y C) Imágenes del desplazamiento y basculamiento del Villafranquiense y de la Terraza Media provocado por las fallas de Las Ramblillas. Figura en color en la web.

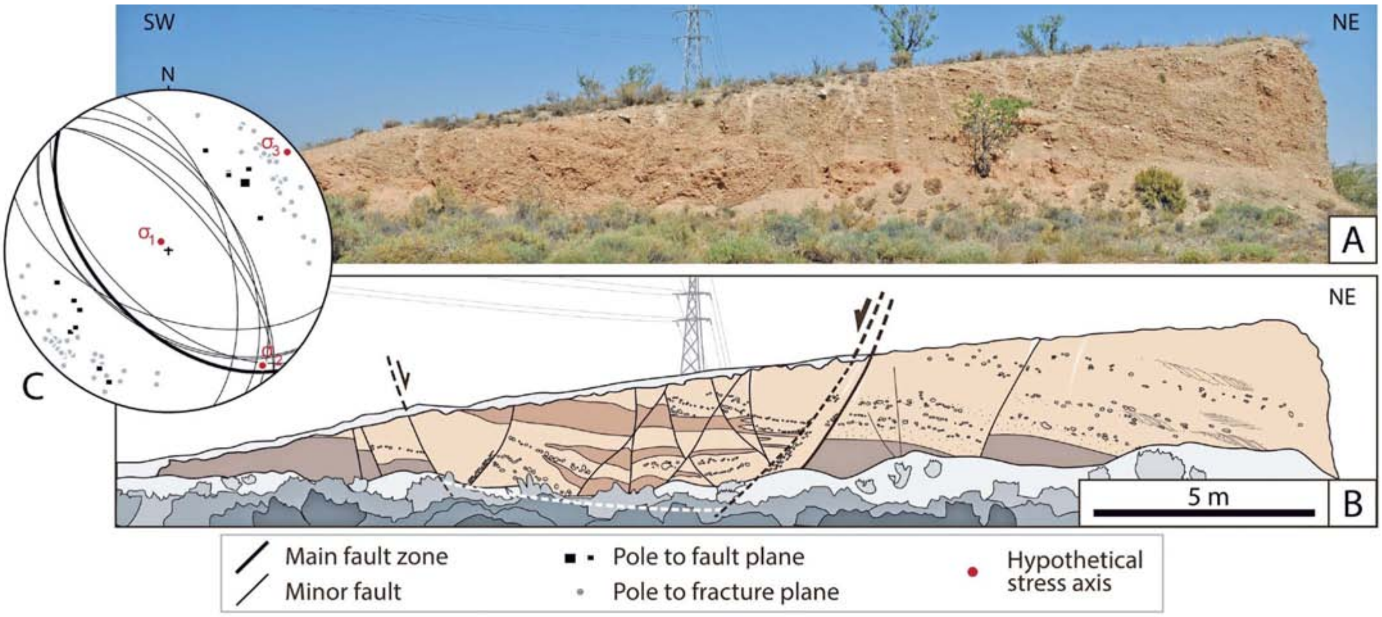

Fig. 4.- A) and B) Normal faults affecting both gravel (light brown in the cross section) and lutites (dark brown) of the Lower Terrace in the northeastern sector of the Cuesta de la Bajada site. C) Stereoplot of the structural elements measured and inferred within the outcrop. Color figure in the web.

Fig. 4.- A) y B) Fallas normales afectando a gravas (marrón claro en el corte) y lutitas (marrón oscuro) de la Terraza Inferior en el sector noreste de Cuesta de la Bajada. C) Estereograma de los elementos estructurales medidos e inferidos en el afloramiento. Figura en color en la web.

axes inferred at Cuesta de la Bajada (σ_1: vertical, σ_3 trend: 050) and with the ENE-WSW trend of the regional extension trajectories for the most recent stress field (Simón, 1989; Arlegui *et al.*, 2005).

In spite of the existence of a large E-W trending structural band affecting Neogene units south of the studied zone (Los Mansuetos-Valdecebro fault zone), transverse faulting is almost absent within the Quaternary deposits exposed in the relay zone. A geophysical survey (magnetometry and georadar, GPR) carried out at El Planizar area, in the centre of the relay zone, yielded similar results concerning the structure of Neogene units beneath the Lower Terrace cover (Lafuente *et al.*, 2011). It showed several NNW-SSE trending anomalies interpreted as minor fractures parallel to the dominant regional trend, whereas no transverse fracture was detected.

Therefore, the hypothesis of an actual or future linkage between the Concud and Teruel faults by means of transfer faults transverse to them (*hard linkage*) becomes weaker. On the contrary, our results suggest that a hypothetical northwards propagation of the main trace of the Teruel Fault seems more probable. If the Teruel Fault finally abuts the NW-SE trending trace of the Concud Fault, the southern segment of the latter could either become an inactive *splay fault* or remain active accommodating a fraction of the total slip.

In any case, at present, both major faults still are independent structures from the geometrical and kinematical points of view according to structural evidences at surface. Unfortunately, the location of seismic foci associated with them is not precise enough for discerning their relationship at depth. Nevertheless, the high displacement gradients near the relay zone indicate that they undergo strong mechanical interaction (Lafuente *et al.*, 2011). We can assess that the Concud and Teruel faults are in an intermediate stage between complete independence and coalescence, a process that already started in Middle Pleistocene times.

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