



## The Río Grío depression (Iberian Chain, NE Spain). Neotectonic graben vs. fluvial valley

*La depresión del Río Grío (Cordillera Ibérica, NE España).  
Graben neotectónico vs. valle fluvial*

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### Abstract

This contribution presents a geomorphological map of the Río Grío depression, located in the central sector of the Iberian Chain, NE Spain. In previous geological maps this depression, *ca.* 30 km long, has been interpreted as an erosional fluvial valley. Geomorphological mapping reveals that it corresponds to a neotectonic graben filled by alluvial fan deposits and subsequently dissected by the axial Grío River and its tributaries. The length of the normal faults indicates that some of the mapped neotectonic structures have the potential to generate earthquakes with moment magnitudes as high as 6.8. This work illustrates that there is limited knowledge on the distribution of recent faults in some sectors of Spain, and that a higher input on the geomorphology and Quaternary geology in the geological maps would help to overcome this weakness.

**Key words:** neotectonic graben; fluvial incision; geomorphological mapping; seismic hazard.

### Resumen

Esta contribución presenta un mapa geomorfológico de la depresión del Río Grío, localizada en el sector central de la Cordillera Ibérica, NE de España. En mapas geológicos previos esta depresión, de unos 30 km de largo, ha sido interpretada como un valle fluvial erosivo. Sin embargo, la cartografía geomorfológica realizada revela que corresponde a un graben neotectónico relleno por depósitos de abanicos aluviales y disectado posteriormente por el Río Grío y sus tributarios. La longitud de las fallas normales indica que algunas de las estructuras neotectónicas cartografiadas tienen potencial para generar terremotos con una magnitud momento del orden de 6.8. Este trabajo ilustra que existe un conocimiento limitado a cerca de la distribución de fallas



recientes en algunos sectores de España y que un mayor protagonismo de la Geomorfología y la Geología del Cuaternario en los mapas geológicos podría ayudar a superar dicho problema.

**Palabras clave:** graben neotectónico; incisión fluvial; cartografía geomorfológica; peligro sísmico.

## 1. Introduction

The Iberian Chain, with a prevalent NW-SE structural grain, is located in the NE of the Iberian Peninsula. This intraplate orogene results from the tectonic inversion of Mesozoic basins occurred from late Cretaceous to Early-Middle Miocene times (orogenic stage). During the postorogenic stage extensional tectonics has generated grabens superimposed on the previous contractional structures. Although an extensional stress field has prevailed in the central sector of the Iberian Range from the Middle Miocene up to the present-day, two main phases of graben development can be differentiated (Capote *et al.*, 2002; Gutiérrez *et al.*, 2008, 2012). The first extensional phase produced the Calatayud and Teruel Grabens, both around 100 km long and filled with Mio-Pliocene terrestrial sediments. The second extensional phase started in the Late Pliocene and generated new tectonic depressions like the Daroca Half-graben and the Jiloca Polje-graben (Fig. 1). Recently, new Plio-Quaternary grabens have been discovered through the elaboration of geomorphological maps, like the Munébrega Half-graben, which is superimposed on the SW margin of the Calatayud Neogene Graben (Gutiérrez, 1996; 1998). Three faulting events younger than 72 ka. have been inferred from a trench dug across the master fault of this fault-angle depression (Gutiérrez *et al.*, 2009). In this work we interpret for the first time the Río Grío valley, located to the NE of the Calatayud Neogene Graben, as a dissected neotectonic graben (Fig. 1).

## 2. Geological setting

The NW-SE-trending Río Grío morphostructural depression is located within the so-called

Calatayud-Montalbán Massif, one of the main Paleozoic outcrops of the Iberian Range. The massif is primarily composed of strongly indurated sandstones and argillites of Precambrian and Paleozoic age. These formations are divided into two main structural units bounded by a major Variscan thrust known as the Datos Thrust (Álvaro, 1991). This structure runs along the Río Grío depression (Gozalo and Liñán, 1988) and is largely concealed by alluvium of the graben fill (Fig. 1). In the studied area, the SW-dipping Datos Thrust shows a linear trace indicating a high angle (Álvaro, 1991), probably caused by subsequent Variscan and/or Alpine folding. The hanging wall of the Datos Thrust, designated as the Badules Unit, is composed of Precambrian, Cambrian and Ordovician formations. The footwall is named the Herrera Unit and in the mapped sector the outcropping rocks include Ordovician and Silurian formations. The structure of the Precambrian and Paleozoic rocks is dominated by NW-SE-trending and NE-verging folds and reverse faults. The Badules Unit is affected by the NW-SE trending and SW dipping Jarque Thrust. North of La Aldehuela, this thrust, called Inogés Fault by Aragonés *et al.* (1980), is situated along the foot of the Vicort Range front, on the southwestern margin of the Río Grío structural depression (Fig. 1). In the northern sector of the Río Grío structural depression the Paleozoic rocks of the Herrera Unit are overlain unconformably by two outcrops of Mesozoic and Paleogene formations affected by Alpine compressional structures (Fig. 1). The Paleogene sediments correspond to folded alluvial fan conglomerates. Locally, subjacent dissolution of the evaporitic Keuper facies, Late Triassic in age, has produced recent deformational structures of gravitational origin with a restricted spatial distribution (Fig. 1).

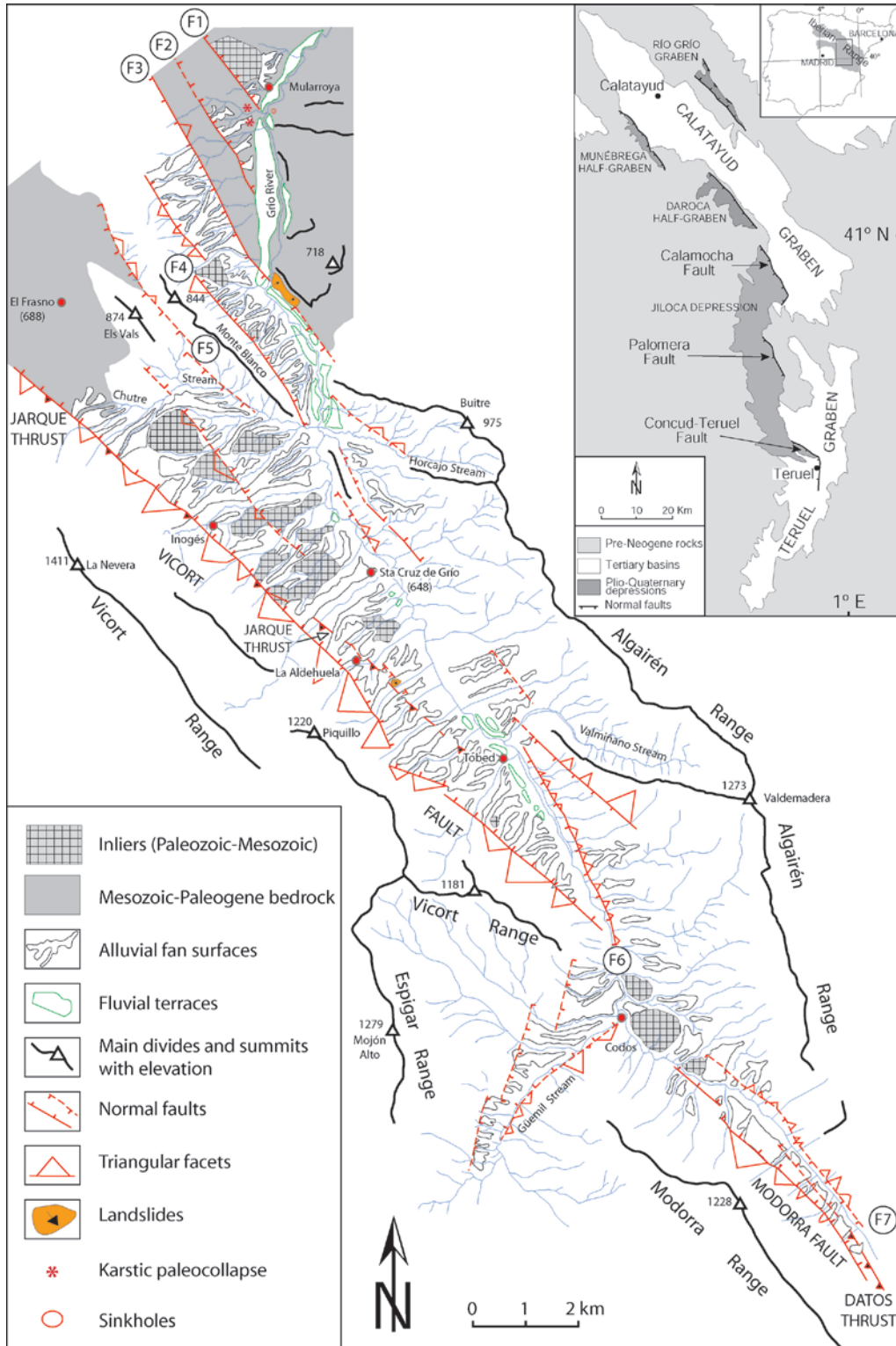


Figure 1. Geomorphological map of the Río Grío Graben.  
 Figura 1. Mapa geomorfológico de la Fosa del Río Grío.

### 3. Description of the Río Grío Graben

The 27 km long and NW-SE trending Río Grío Graben is flanked by prominent ranges made up of resistant Paleozoic rocks, the Vicort-Modorra Range to the SW, and the Algairén Range to the NE. The Vicort-Modorra Range constitutes an uplifted horst that separates the Calatayud Graben and the Río Grío Graben. The Río Grío morphostructural depression is filled with alluvial fan deposits that have been deeply dissected by the longitudinal Grío River and its tributaries. The graben has a markedly asymmetric geometry. The southwestern margin is controlled by two linear and well-defined normal faults; the 15.5 km long Vicort Fault, and the 5.9 km long Modorra Fault. North of La Aldehuela the trace of NE-dipping Vicort Fault coincides with that of the SW-dipping Jarque or Inogés Thrust mapped by Aragonés *et al.* (1980). Both the Vicort and Modorra faults have a conspicuous geomorphic expression, controlling linear mountain fronts with triangular facets up to 230 m high (Fig. 2). The trace of the fault coincides with the sharp rectilinear apical boundary in the alluvial fans deposited on the hanging wall. Unfortunately, no clear exposures showing

the expectable normal fault contact between the alluvial fan sediments and the Paleozoic rocks of the uplifted blocks have been found along these range fronts. Some of the morphometric parameters of the mapped faults are presented in Table 1. The Vicort and Modorra faults are separated in Codos area by a gap with a transverse tectonic depression controlled by NNE-SSW- and NE-SE-trending cross-faults, and drained by the Güemil River.

The northeastern margin of the depression is controlled by a series of shorter faults with a less obvious geomorphic expression. The trace of some of these faults coincides with the scarped northeastern margin of the Grío River fluvial valley (faults F7, F6 and southern portion of F3). Consequently, the triangular facets mapped along the northeastern margin of the Río Grío valley, generally steeper, may have a mixed tectonic and fluvial origin. The fault situated SE of Codos (F7) runs next and parallel to the Datos Thrust, suggesting that it may correspond to the postorogenic negative reactivation of the latter. In its NW portion this fault (F7) has offset alluvial fan deposits (Figs. 3 and 4) creating a downhill-facing scarp up to 37 m high. The anomalous



Figure 2. Triangular facet >200 m high south of La Aldehuela associated with the Vicort Fault. Arrow points at the facet apex.

*Figura 2. Faceta triangular de >200 m de altura al sur de La Aldehuela asociadas con la Falla de Vicort. La flecha señala el ápice de la faceta.*

Table 1. Strike (St) and length (L) of the main mapped faults, dominant lithology (Lith) in the range front, height (H) and slope (S) of the largest triangular facet and expected moment magnitudes based on the fault length and the regressions proposed by Wells and Coppersmith (1994) for normal faults (Mw W-C) and by Stirling *et al.* (2002) for preinstrumental earthquakes (Mw S). Lithology: Q: Quartzite; L: Limestone; C: Conglomerate; A: Argillite.

Tabla 1. Dirección (St) y longitud (L) de las principales fallas cartografiadas, litología dominante (Lith) en el frente montañoso, altura (H) y pendiente (S) de las facetas triangulares más grandes y las magnitudes momento basadas en la longitud de la falla y las regresiones propuestas por Wells y Coppersmith (1994) para fallas normales (Mw W-C) y por Stirling *et al.* (2002) para terremotos preinstrumentales (Mw S). Litología: Q: Cuarzita; L: Caliza; C: Conglomerado; A: Arcillas.

Fault	St	L	Lith	H	S	Mw W-C	Mw S
Vicort	135	15.5	Q	230	27	6.2	6.8
Modorra	136	5.9	Q	140	23	5.9	6.5
F1	148	1.7	L				
F2	147	2.8	L			5.4	6.2
F3	147	6.5	C, L	60	21	5.9	6.5
F4	146	5.8	Q	60	19	5.9	6.5
F5	148	5	Q	50	26	5.8	6.4
F6	155	4.5	A, Q	60	13	5.7	6.4
F7	137	4.1	Q	90	30	5.7	6.4



Figure 3. Normal fault F7 juxtaposing alluvial fan deposits against strongly deformed paleozoic rocks.  
 Figura 3. Falla normal F7 poniendo en contacto depósitos de abanico alluvial con rocas paleozoicas intensamente deformadas.

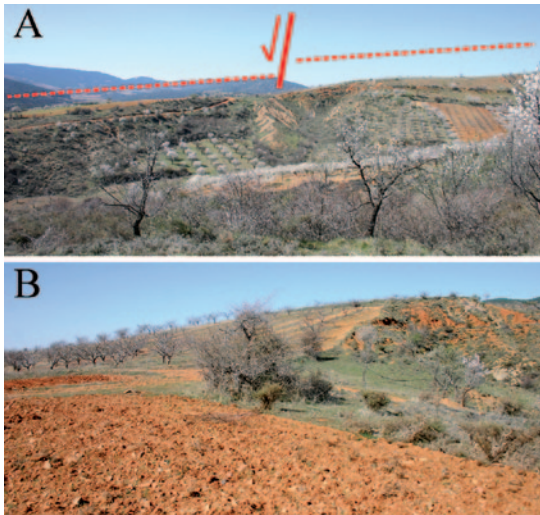


Figure 4. Lateral (A) and oblique (B) view of alluvial fan surface offset by normal fault F7 on its NW tip sector.  
*Figura 4. Vista lateral (A) y oblicua (B) del escarpe en un abanico aluvial producido por la falla normal F7 en su extremo NO.*

oblique orientation of some tributary drainages in the NE margin of the depression seems to be controlled by uplifted (Horcajo Stream) or backtilted fault blocks (Valmiñano Stream), in combination with stepovers.

The northern sector of the graben shows a more complex structure comprising a series of horsts and grabens around 1 km wide controlled by NW-SE-trending normal faults with an en échelon right-stepping arrangement. Here, the Grío River constitutes an oblique drainage with respect to the fault blocks, rather than a longitudinal one. These faults are defined by linear scarps with triangular facets and an abrupt termination of the alluvial fan units. The graben bounded by fault F5 and the Vicort Fault corresponds to the southernmost sector of the so-called Morés Graben, in which Triassic formations are downfaulted between fault blocks of Paleozoic rocks. The



Figure 5. Badlands landscape and hoodoos (pedestals) developed in highly brecciated paleozoic rocks associated with fault F6 (Los Abuelos de Tobed).  
*Figura 5. Paisaje de cárcavas y chimeneas de hadas (pedistales) desarrolladas en rocas paleozoicas intensamente brechificadas asociadas a la falla F6 (Los Abuelos de Tobed).*

termination of these faults in our map is based on the disappearance of triangular facets and alluvial fan sediments in the down-dropped block. A normal fault contact between the alluvial fan sediments and the footwall bedrock has been inferred from an outcrop of fault F1 southwest of Mularoya. To the NE of Fault F2 and at the left margin of the Grío Valley, a small drainage has exposed alluvial fan deposits affected by several vertical failure planes. A N145E strike has been measured in one of these fault planes. Between faults F1 and F2, in cuttings of the A-2302 and the old N-II roads, the alluvial fan deposits are affected by failure planes attributable to paleocollapse structures caused by the karstification of the underlying Triassic evaporites. In a cutting of the abandoned N-II road, tilted alluvial fan sediments are down-dropped within highly brecciated early Jurassic carbonate rocks. We attribute this structure that does not appear in the adjacent cutting to evaporite interstratal dissolution and collapse.

The Río Grío graben depression is largely occupied by dissected alluvial fans. The majority of these fans are situated to the west of the Grío River. In the northern sector the NE inclination of the fan surfaces is controlled by the NW-SE trending horst and graben structure, rather than being directed towards the Grío River. The alluvial fan deposits overlie a very irregular paleorelief and show a highly variable thickness, typically higher than 30 m. Locally, the alluvial fill is interrupted by rounded inliers of Paleozoic or Mesozoic rocks that protrude over the top of the fan surfaces. In Tobed area, where the base of the basin fill is probably below the current base level, we have measured a minimum thickness of 90 m of alluvium. The alluvial sequence is dominated by tabular bodies of massive angular gravels and boulders with a sandy matrix and of massive sands with scattered clasts (sheet-flood deposits). Some gravel beds with a matrix-supported texture correspond to debris flow facies. Several terrace levels have been mapped downstream of Codos inset with respect to the alluvial fan units. This morphostratigraphic sequence records two main evo-

lutionary phases: (1) A first period of alluvial filling controlled by tectonic subsidence. (2) A second period in which tectonic subsidence was not high enough to counterbalance the incision trend of the drainage network. Probably, the transformation from an aggradational to an incisional tectonic basin was determined by alterations in the drainage network (i.e. base level drops, captures) that induced a change from a poorly drained basin to a basin effectively drained by a high gradient axial stream. In the absence of chronological information on the alluvial fan sediments, based on their geomorphic setting and regional paleogeographic evolution, we estimate that it may have a Plio-Quaternary age.

The alluvial fan deposits and surfaces are locally offset by intrabasinal faults. The Paleozoic rocks associated with these faults are commonly strongly crushed and their low resistance to erosion favour an anomalous development of badlands (Fig. 5). The faults dipping towards the valley produce downhill-facing scarps (fault between Modorra Fault and F7), whereas antithetic faults dipping towards the basin margins are expressed as uphill-facing scarps (Fig. 6). A GPR survey carried out across the antisllope scarp situated SE of La Aldehuela has allowed us to infer tilted beds truncated by a steep SW dipping failure plane (Fig. 6)

#### 4. Final considerations

One of the main tasks that geologists have to undertake for seismic hazard assessment is the identification and mapping of recent faults that might have the potential to generate earthquakes. Based on the geomorphological map presented, some of the neotectonic faults that control the Río Grío graben are long enough to produce earthquakes with damaging magnitude (Table 1). However, the Río Grío valley has been interpreted as an erosional fluvial valley in all the geological maps published by the Spanish Geological Survey, including the geological cross-sections (Aragóns *et al.*, 1980; Olivé *et al.*, 1983). Additio-

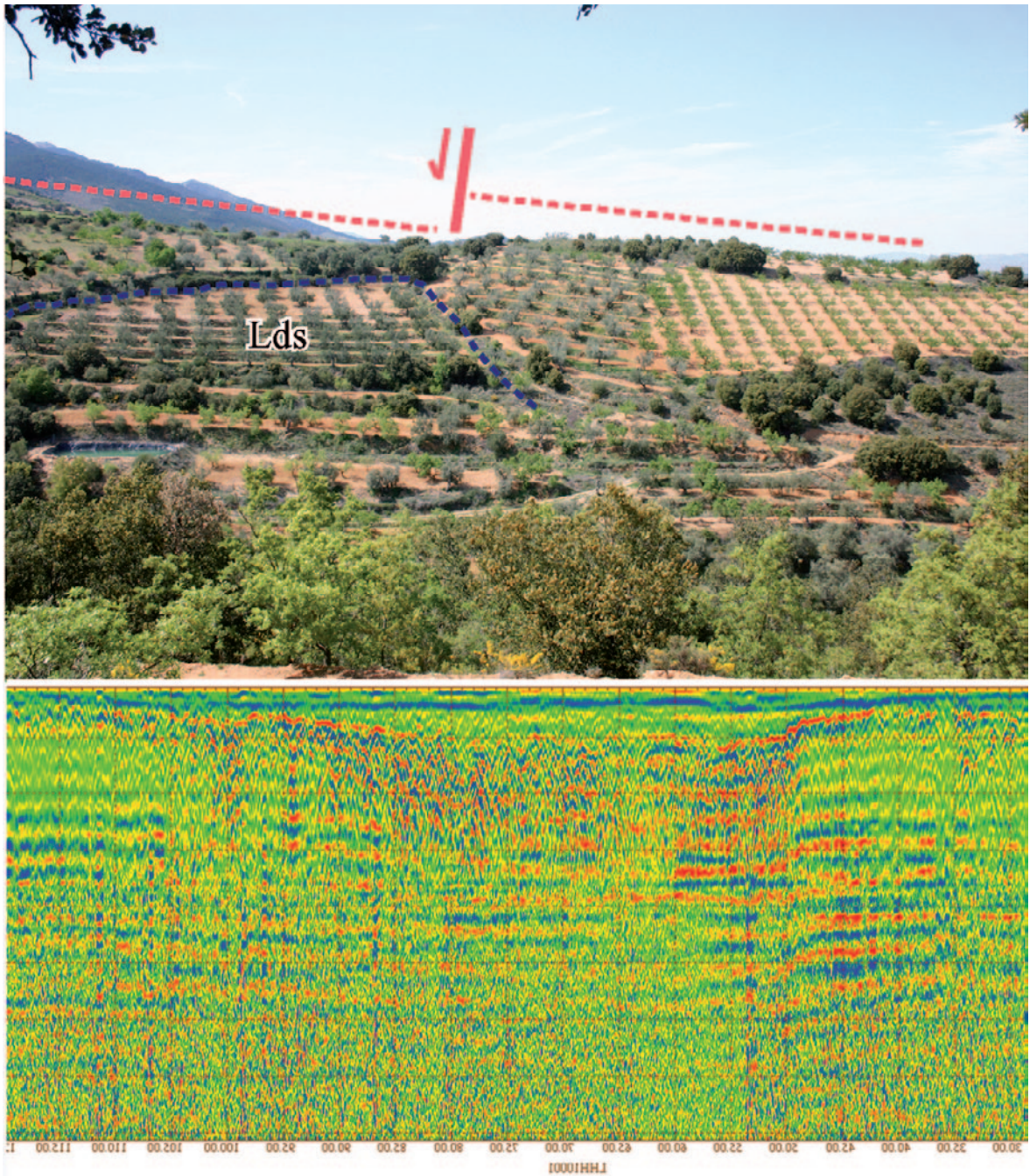


Figure 6. Uphill-facing scarp produced by an antithetic fault SE of La Aldehuela. Lds: landslide. GPR survey performed with 200 MHz antennas across the antislope scarp.

*Figura 6. Escarpe orientado ladera arriba generado por una falla antitética al sureste de La Aldehuela. Lds: deslizamiento. El perfil de georradar se obtuvo con antenas de 200 MHz perpendicularmente al escarpe a contrapendiente.*



nally, a detailed geological map recently elaborated for the Mularoya Reservoir Project does not represent any of the Plio-Quaternary faults depicted in our geomorphological map. Consequently, those cartographic works lead to an underestimation of the seismic hazard in the area. Conversely, the 1:1.000.000 Neotectonic Map of Spain, largely derived from geomorphological maps, depicts schematically the Río Grío valley as a linear depression bounded by two long neotectonic faults (Baena *et al.*, 1998). Probably, some of the reasons why the neotectonic faults were overlooked in the geological maps include: (1) Most of the faults are not exposed. (2) Their identification needs to be based on geomorphic criteria and careful mapping of Quaternary sediments, traditionally two secondary aspects in the elaboration of classical geological maps in Spain. This work suggests that the current knowledge on the distribution of neotectonic faults in some sectors of Spain may be quite limited and that geomorphology and Quaternary geology should receive more attention when producing geological maps in areas where young faulting may occur (McCalpin, 2008). This preliminary work will serve as the basis to conduct geophysical surveys and trenches aimed at checking the inferred faults and unravelling their paleoseismic record and seismogenic potential.

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