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Tectonic beheading of fluvial valleys in the Maestrat grabens (eastern Spain): Insights into slip rates of Pleistocene extensional faults

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ABSTRACT

Interaction between faulting and landscape evolution in regions of active tectonics allows us to use subtle geomorphological markers for estimating fault slip rates. Geomorphic features of two valleys connected with the bottom of the Alcalà de Xivert graben, at the Maestrat graben system (eastern Spain), suggest that they correspond to the lowest segments of ancient valleys whose original heads were located at the axis of the neighbouring Irta range. They were beheaded owing to displacement of the Torreblanca and Irta faults during a period of active extensional faulting in Middle Pleistocene times. These faults produced a negative inversion of the relief, sinking a narrow graben (the Ametler graben) at the middle of the Irta range whose alluvial infill buried the midsegments of the beheaded valleys. This hypothesis has been tested by applying two geomorphic indices, the Stream-gradient index (SL) and the Valley width/height ratio (V_f), as well as by considering surface and subsoil information about the sedimentary infill of the Ametler graben. From this evolutionary model, after reconstructing hypothetical longitudinal profiles of the ancient rivers, and taking into account a new absolute age obtained for the alluvial infill of the Ametler graben, slip rates at the northern segment of the Torreblanca fault have been approached. The throw rate has been constrained between a minimum of 0.04–0.07 mm/year for the last 1.9 to 2.6 Ma, and a maximum of 0.26–0.30 mm/year for the last 253.3 ± 18.0 ky. These values are comparable to those averaged on other active faults in the central-eastern Iberian Chain for the overall Late Pliocene–Pleistocene times. Nevertheless, the Torreblanca fault shows exceptionally high activity within the context of the Maestrat and Catalonian grabens, which can explain its deep imprint in landscape evolution.

1. Introduction

The Maestrat graben system (eastern Spain) is a part of the onshore structures produced by Neogene–Quaternary rifting at the Valencia Trough (Roca and Guimerà, 1992; Vegas et al., 1979). It initiated during the Late Oligocene to Early Miocene, and developed through successive faulting episodes along Late Miocene to Pleistocene times (Simón, 1984). Vertical displacements of the order of 10^1 to 10^2 m occurred on a number of faults by the Early to Middle Pleistocene, interacting with the fluvial landscape and inducing significant changes on it (Pérez and Simón, 1993; Simón et al., 1983).

In particular, the drainage network at the eastern margin of the Alcalà de Xivert graben (Fig. 1) could be modified owing to sinking of a narrow graben (the Ametler graben) within the neighbouring Irta horst. As can be clearly seen on the Digital Elevation Model of Fig. 2, this graben has the appearance of being originally a small portion of the southern Irta horst, then downthrown by the combined effect of two conjugate normal faults. Two valleys draining into the Alcalà de Xivert depression, the Portell and La Coma valleys (Fig. 2), show an anomalous morphology that was interpreted by Salvador and Simón (1990) as a result of tectonic beheading. According to such hypothesis, they should actually represent the lower segments of longer valleys that, by the Pliocene–Pleistocene transition, had their head at the Irta range divide, and were then cut by the Torreblanca fault that makes the western boundary of the Ametler graben (Fig. 1c).

Beheaded valleys are not rare in regions where active, either horizontal or vertical tectonic displacement occurs. Certain authors (e.g. Bishop, 1995; Miller and Slingerland, 2006; Schmidt, 1989) have understood the notion of 'beheading' in a different sense to that used in the present work: headward extension of a drainage system at an expense of another, the valleys and ridges being broadly transferred (relief advection) across the drainage divide. Valleys can be also beheaded by piracy owing to rapid, 'aggressive' erosion of other neighbouring rivers (e.g. Ota et al., 2006), showing associated capture elbows and knickpoints not related with tectonic faulting. Nevertheless, the most conspicuous cases occur where fluvial channels

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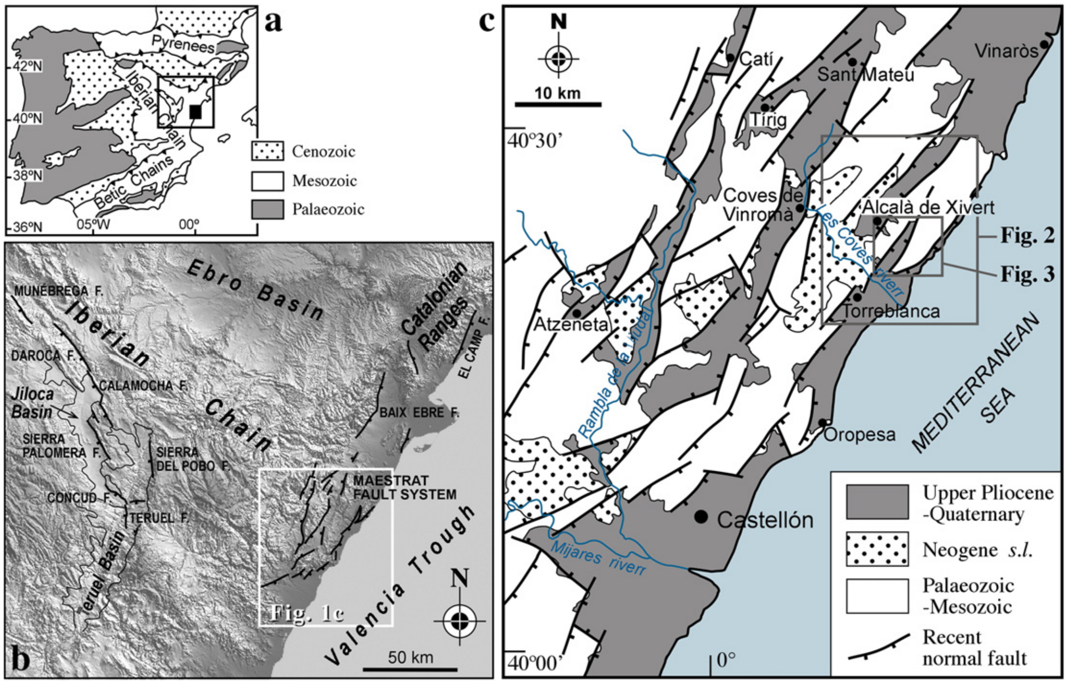

Fig. 1. (a) Location of the study area (solid black square) within the Iberian Peninsula. (b) Digital Elevation Model of the central-eastern Iberian Chain and southern Catalonian Ranges (open square in a) showing the main active faults. (c) Geological sketch of the Maestrat graben system.

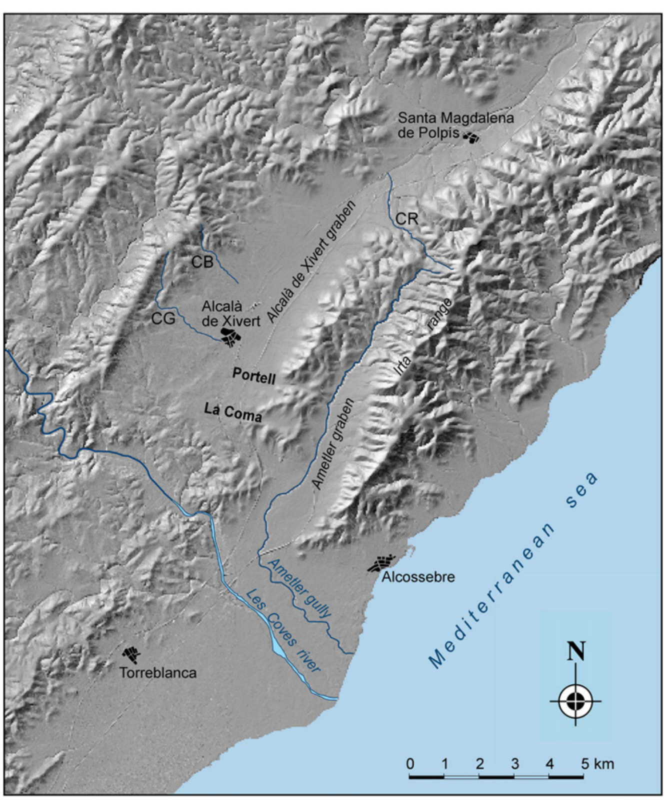

Fig. 2. Digital Elevation Model of the Alcalà de Xivert and Ametler grabens (from Centro Nacional de Información Geográfica–CNIG, 5 × 5-m grid size, reference geodetic system ETRS89, UTM grid zone 31) showing location of the studied valleys (Portell and La Coma), as well as other valleys taken as a reference for morphometric analysis: Coveta Rotja gully (CR), Clot del Gitano gully (CG), and Corral Blanc gully (CB). See location in Fig. 1.

have been completely truncated by faults and disconnected from their former headwaters (tectonic beheading).

Beheading by strike-slip faults takes place where the rate of horizontal displacement is much larger than that of lateral migration of the river that crosses the fault. Identifying the geometry of the ancient valley and dating the valley initiation have long been used to estimate horizontal displacements (e.g. Kaneda and Okada, 2008; Reheis and Sawyer, 1997; Shabanian et al., 2009; Wesnousky, 2005). Beheaded streams (as well as streams that have been offset or deflected without losing its continuity) have been successfully utilized to determine the slip per event, length of rupture, and magnitude of prehistoric earthquakes associated to strike-slip faults (e.g. Lindvall et al., 1989; Sieh and Jahns, 1984; Zhang et al., 1987).

Beheading by extensional faults has also been described. The involved valleys can be either *consequent* or *obsequent* with the structure, i.e. they can flow, respectively, in the sense of tectonic slope (e.g. Central Apennines, Italy; Whittaker et al., 2007) or in the opposite sense (e.g. major transverse drainages cut by frontal normal faults at Sierra Nevada, U.S.A.; Wakabayashi and Sawyer, 2001). The present-day beginning of channels consequent to normal faults (as well as those that were beheaded by strike-slip faults) is usually located close to a fault scarp. The drainage apparently comes from a positive relief (although this is not its original head), so that the landscape setting does not contain any noticeable anomaly. On the contrary, beheaded channels obsequent to dip-slip faults loose their original heads and develop wind gaps in the footwall (e.g. Morewood and Roberts, 1999, 2002).

The latter constitutes the preliminary hypothesis for the Portell and La Coma valleys. In this paper, it is tested by analysing their morphometric parameters from detailed topographic maps and a Digital Elevation Model. Surface and subsoil information about the sedimentary fill of the Ametler graben is also used for contrasting such interpretation. The results will be placed within the framework of recent tectonic evolution of the Maestrat graben system. In particular, they are used to approximate recent slip rates on the concerned, Torreblanca and Irta faults, and to compare them with other extensional faults in eastern Iberia.