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Geomorphic analysis of the Sierra Cabrera, an active pop-up in the constrictional domain of conjugate strike-slip faults: The Palomares and Polopos fault zones (eastern Betics, SE Spain)

Flavio Giaconia [a,*], G. Booth-Rea [a,b], J.M. Martínez-Martínez [a,b], J.M. Azañón [a,b], J.V. Pérez-Peña [b]

[a] Dpto. Geodinámica, Instituto Andaluz de Ciencias de la Tierra (CSIC-UGR), Campus Fuentenueva S/N, 18002, Granada, Spain
[b] Dpto. Geodinámica, Universidad de Granada (UGR), Campus Fuentenueva S/N, 18002, Granada, Spain

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ABSTRACT

The NNE–SSW sinistral Palomares and the conjugate dextral WNW–ESE striking Polopos fault zones terminate in the Sierra Cabrera antiform. In order to test the Quaternary activity and topographic relief control in the termination of these fault zones, here we present new qualitative and quantitative geomorphic analyses supported by a new structural map of the region. The main mountain fronts of the Cabrera antiform are formed by the North and South Cabrera reverse faults that merge laterally into the Palomares and Polopos faults, respectively. These faults produce knickpoints, stream deflections, complex basin hypsometric curves, high *SLk* anomalies and highly eroded basins in their proximity. Furthermore, the drainage network shows an S-shaped pattern reflecting progressive anticlockwise rotation related to the sinistral Palomares fault zone. The estimated uplift rates determined by the integration between mountain front sinuosity index and valley floor width to height ratio are larger than those obtained for strike-slip faults in the eastern Betics. These larger uplift rates with our geomorphic and structural dataset indicate that the topographic relief of the Sierra Cabrera antiform is controlled by reverse faults that form a pop-up structure in the constrictional domain between the larger Palomares–Polopos conjugate strike-slip faults. Existing GPS geodetic data suggest that the North and South Cabrera reverse faults probably accommodate a large part of Africa–Iberia convergence in the region.

1. Introduction

Geomorphic analyses are very productive in semiarid zones like SE Spain, where landforms related to active tectonics are preserved for long periods (Silva et al., 2003). Furthermore, geomorphic indices are tools to characterize sectors deformed by active faults with low to moderate deformation rates (Gràcia et al., 2006; Keller and Pinter, 2002; Pedrera et al., 2009; Pérez-Peña et al., 2010). In regions affected by strike-slip faults, like the eastern Betics, displacement generates important topographic gradients forming both uplifted ranges and sedimentary depocentres in antidilational and dilational jogs, respectively (Sibson, 1986; Sylvester, 1988). Similarly, thrust systems and associated folds control the development and evolution of alluvial and fluvial systems in response to tectonically induced local base-level variations, together with fault linkage and time–space migration of folds (Pedrera et al., 2009; Ramsey et al., 2008). Furthermore, creation of new fault segments produces migration of active sedimentary depocentres and variations in the topography and drainage network (Booth-Rea et al., 2004a; Ollier, 1981; Walker and Jackson, 2002). In the southeastern Betics the main positive topographic reliefs coincide either with antidilational jogs related to strike-slip faults or with antiformal structures that define the Sierras in the area (e.g. Montenat and Ott d'Estevou, 1990).

Sierra Cabrera is a key area to evaluate the nature of active tectonics in the eastern Betics because three of the main active faults in SE Spain, the Carboneras, the Palomares and the Polopos fault zones, converge and terminate there. Contrasting with the pure strike-slip Neogene activity of these faults (Bousquet, 1979; Faulkner et al., 2003; Gràcia et al., 2006; Montenat et al., 1990; Ott d'Estevou et al., 1990), the Quaternary activity of the Carboneras and the Palomares fault zones appears to be oblique-slip along their terminations (Bell et al., 1997; Booth-Rea et al., 2003, 2004a; Buforn et al., 1988, 1995, 2004; Reicherter and Reiss, 2001).

The N90–100°E dextral Polopos fault zone, conjugate of the Palomares fault zone, bounds the southwestern termination of the Sierra Cabrera antiform and has been active during the Pleistocene with a global transpressive regime (Giaconia et al., 2012). This fault zone merges into N50–60°E reverse fault segments, here named the South Cabrera reverse faults, in the southeastern corner of the Sierra Cabrera. The Carboneras fault is a sinistral strike-slip fault active during the Neogene to Quaternary (Bousquet, 1979; Faulkner et al., 2003; Gràcia et al., 2006; Montenat et al.,

* Corresponding author. Tel.: +34 622605328.
E-mail addresses: flavio@ugr.es, flavio@iact.ugr-csic.es (F. Giaconia).

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1990; Ott d'Estevou et al., 1990). This fault worked as a transform fault system accommodating differential extension between the Níjar and other postorogenic basins to the NW of it and the volcanic Cabo de Gata terrain to the SE (Rutter et al., 2012). Its Plio-Quaternary activity appears to be oblique-slip according to the field data (Bell et al., 1997; Buforn et al., 1988, 1995, 2004; Reicherter and Reiss, 2001; Rutter et al., 2012). The Plio-Quaternary activity of the Palomares fault zone is characterized by a sinistral-normal displacement that uplifts its eastern block, represented by the Sierra Almagrera. Toward the south, Palomares fault segments turn and splay out into reverse faults in the northern limb of the Sierra Cabrera antiform (Booth-Rea et al., 2003, 2004a). In this paper we refer to these faults as North Cabrera reverse faults. GPS geodetic studies in the southeastern Betics show deformation rates of 1–1.5 mm yr^{-1} on the coast, roughly parallel to the NW–SE direction of the Africa–Eurasia plate convergence, while the stations inland exhibit insignificant motion with respect to the stable part of the Eurasian plate (Echeverria et al., 2011). This indicates that the majority of the convergence between Africa and Eurasia in the area is accommodated along structures located near the coast, like the Sierra Cabrera antiform and associated structures.

In this paper we carry out a thorough geomorphic analysis of the Sierra Cabrera ridge supported by a new geological and structural map inferring that strike-slip displacement along the Polopos and Palomares fault zones has been accommodated by reverse faulting in the southern and northern hillslopes of the ridge by the South and North Cabrera reverse faults, respectively. This reverse tectonic regime in the Sierra Cabrera antiform, together with the epeirogenic uplift of the southern Betics (Braga et al., 2003), results in a strong dissection of its hillslopes by the Aguas and Alias river systems, to the north and to the south, respectively. Because of this morphotectonic context the Quaternary alluvial and fluvial deposits are missing at the foot of the hillslopes impeding the timing of faulting and fault slip-rate determination. Thus, the objective of this paper is to test the presence of active or recent reverse faults that may control the topographic relief of the Sierra Cabrera antiform and surrounding Neogene basins (e.g. Vera and Níjar basins), using both qualitative and quantitative geomorphic analyses. Quantitative analyses were conducted calculating the following geomorphic indices: mountain-front sinuosity, valley floor width-to-height ratio, drainage basin asymmetry factor, basin hypsometric curve and integral, and the stream-length gradient index normalized by the graded river gradient (*SLk* index).

2. Structural framework

The southeastern Betics are characterized by the occurrence of Neogene basins formed during Miocene extensional tectonics (Booth-Rea et al., 2004b, 2005; Martínez-Martínez and Azañón, 1997). Later, Late Miocene to present convergence between Africa and Iberia (Dewey et al., 1989; McClusky et al., 2003; Serpelloni et al., 2007) produced tectonic inversion of the Miocene extensional basins and development of folds, reverse and strike-slip fault systems (Booth-Rea et al., 2004a; Comas et al., 1999; Montenat and Ott d'Estevou, 1990; Weijermars et al., 1985). Thus, most of the sedimentary cover occurs in synclines among E–W- to ENE–WSW-elongated antiformal ridges, where the metamorphic basement crops out bounded by folded extensional detachments (Fig. 1). This basement is formed by several metamorphic complexes belonging to the Alboran domain, a terrain that collided with the South Iberian and Maghrebian passive margins during the Miocene, forming the Gibraltar arc and the Betic and Rif cordilleras (Balanyá and García-Dueñas, 1987; Booth-Rea et al., 2007; Martínez-Martínez and Azañón, 1997; Platt et al., 2003). The Sierra Cabrera antiform is an example of these elongated antiformal ridges where metamorphic rocks crop out, surrounded by Miocene to Quaternary sediments of the Sorbas–Tabernas, Vera and Níjar basins (Fig. 1).

The Sierra Cabrera antiform is located in the termination of three strike-slip faults developed in the NW–SE Late Miocene to present convergent setting (Fig. 2). These are the sinistral Carboneras (Bell et al., 1997; Gràcia et al., 2006) and Palomares (Booth-Rea et al., 2004a; Bousquet, 1979) fault zones that end in the eastern termination

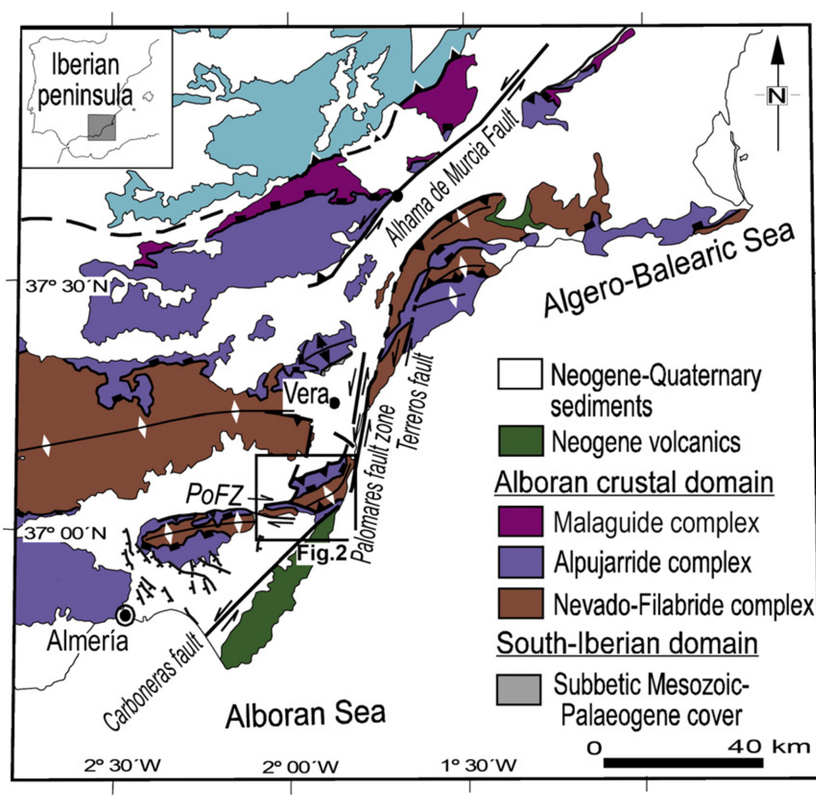

Fig. 1. Geological sketch of the southeastern Betics highlighting the studied area after Giaconia et al. (2012). PoFZ: Polopos fault zone.