Relief rejuvenation in response to intraplate neotectonics in the Betics foreland (southern Spain)

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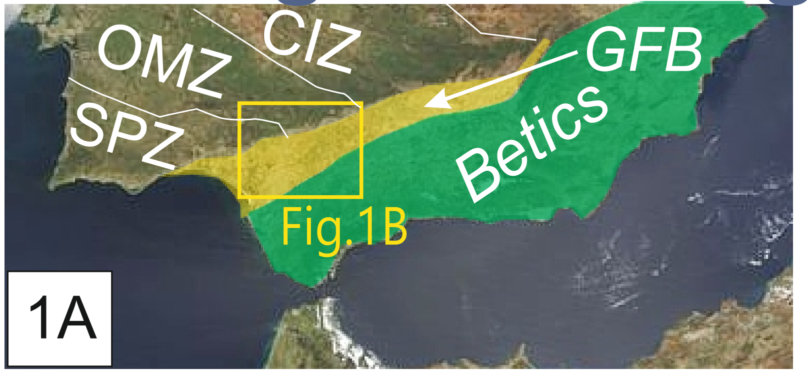
Introduction

Relief rejuvenation of ancient areas often occurs in response to intraplate deformation. In these long-lived areas, characterized by previous mechanical discontinuities, rejuvenation may be strongly controlled by fault reactivation, as these structures must play a significant role on strain localization and strain partitioning. We analyze these topics in the Betics foreland, in the so-called forebulge. It consists of a flexural WSW-ENE relief, related to the orogenic load of the Betics, an alpine chain mainly stacked during the Miocene. The southern limit of the forebulge coincides with a sharp topographic escarpment separating the foreland and the Guadalquivir river basin (i.e. the Betics foreland basin). We have combined structural and geomorphic tools, the latter including both qualitative and quantitative techniques (geomorphic indexes). Our analysis are focused on tributaries drainage networks located on the Guadalquivir river right bank, covering

Geological setting



The studied sector is mainly composed of paleozoic rocks belonging to both the Ossa-Morena and the South-Portuguese zones. The Permian rocks of the Viar basin mark the limit between both zones, and coincide with the current Viar river catchment, a NW-SE elongated topographic depression (Fig.1B&6A).

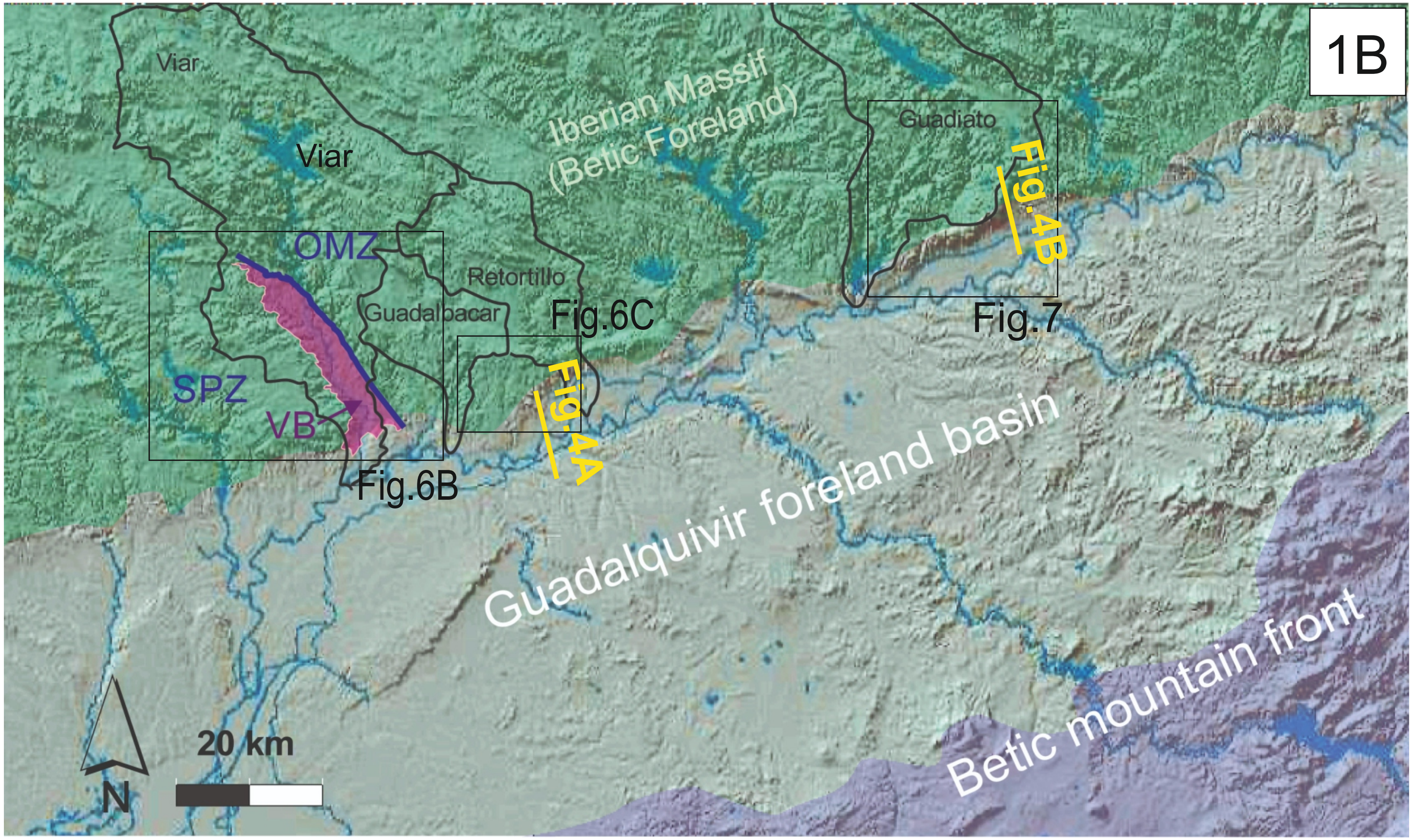


Fig.1.A) Location of Fig1B in the Southern Iberian Peninsula; CIZ: Central Iberian Zone, OMZ: Ossa-Morena Zone, SPZ: South-Portuguese Zone, VB:Viar Basin, GFB: Guadalquivir foreland basin. B) Relief map showing the southern topographic escarpment of the Iberian Massif as well as the betic mountain front.

Qualitative analysis (i)

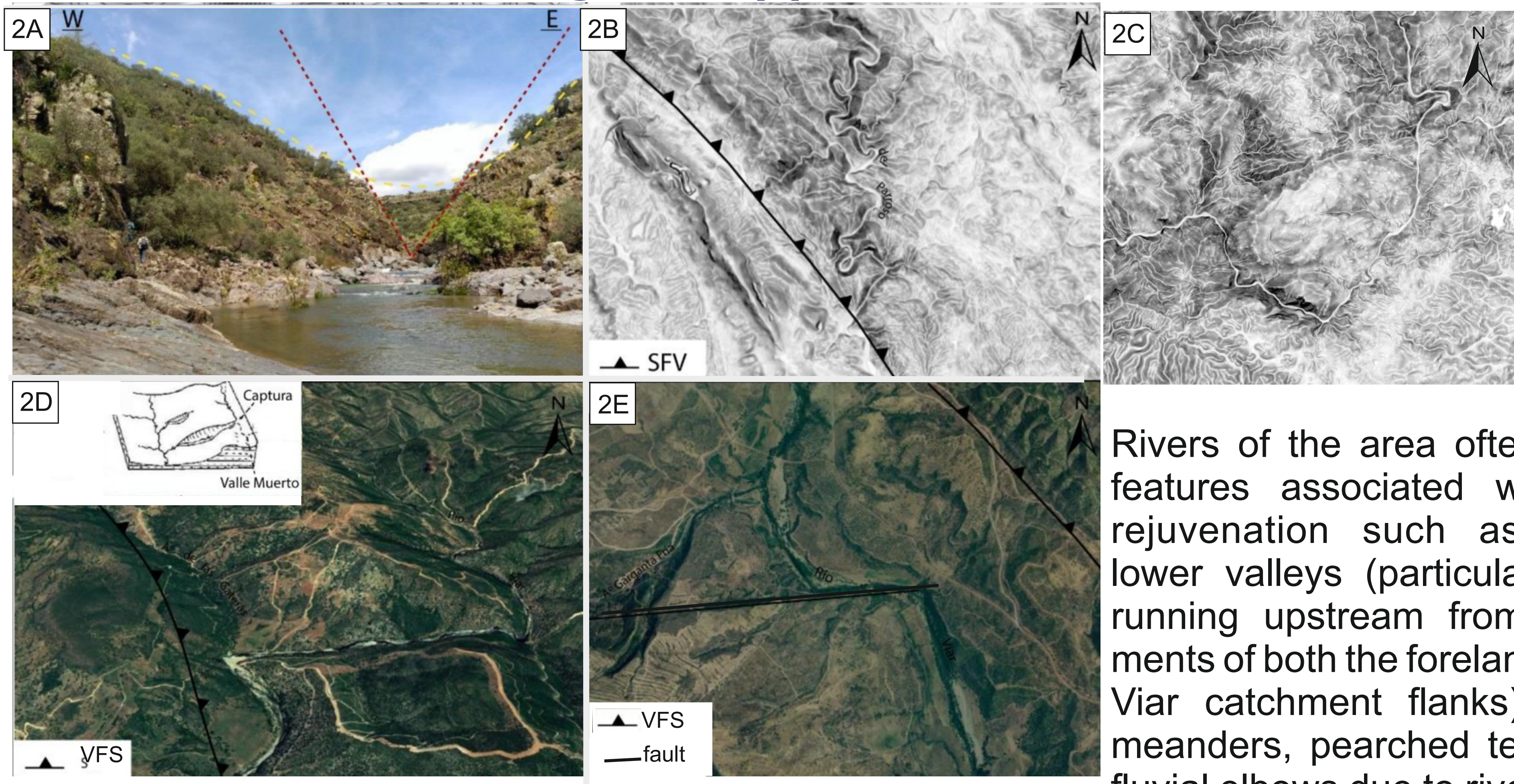
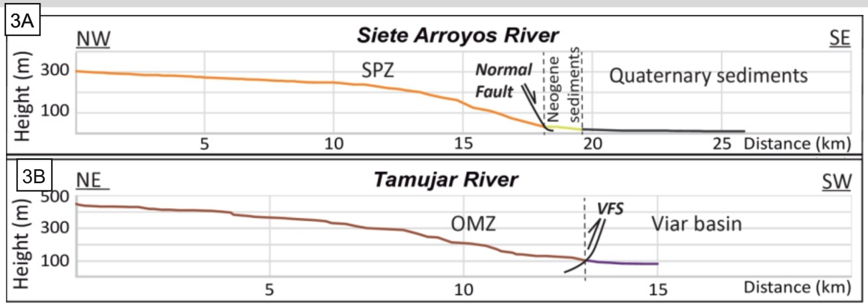


Fig.2. A) Incised lower course of a right bank tributary of the Viar river. B) Incised meanders in a left bank tributary of the Viar river. C) River elbow along the Guadiato, due to slope inversion (note an incised meander at the up-right corner), D&E) River elbows along Viar course due to river capture and faul-related deflection, respectively.

Rivers of the area often display features associated with relief rejuvenation such as incised lower valleys (particularly when running upstream from escarpments of both the foreland and the Viar catchment flanks), incised meanders, pearched terraces or fluvial elbows due to river capture and fault-related stream deflections (Fig.2). Their lon profiles also deviate frecuently from the equilibrium (concave) profile shape (Fig. 3A&B and 5A-F).

Qualitative analysis (ii)

The incised valleys are separated by flat subhorizontal summits, displaying often a stepped geometry (Fig. 3C&D), which probably represent remnants of a erosional surface Paleogene in age (Rodríguez Vidal and Díaz del Olmo, 1994), or even younger. They are tens of meters elevated aboved the Guadalquivir basin (the probable base level of the erosional surface). Indeed, Neogene marine sediments crop out locally on top of this flat interfluves (Fig. 4A&B).



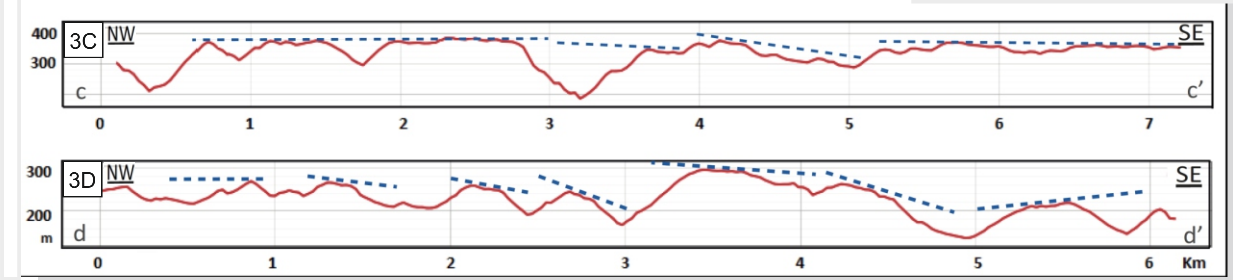


Fig.3. A) & B) Long profiles of a Guadalquivir river tributary and a left bank Viar basin tributary, respectively (see Fig.5A). C) & D) Topographic profiles of the SW and NE Viar catchment flanks (see location on Fig 6A).

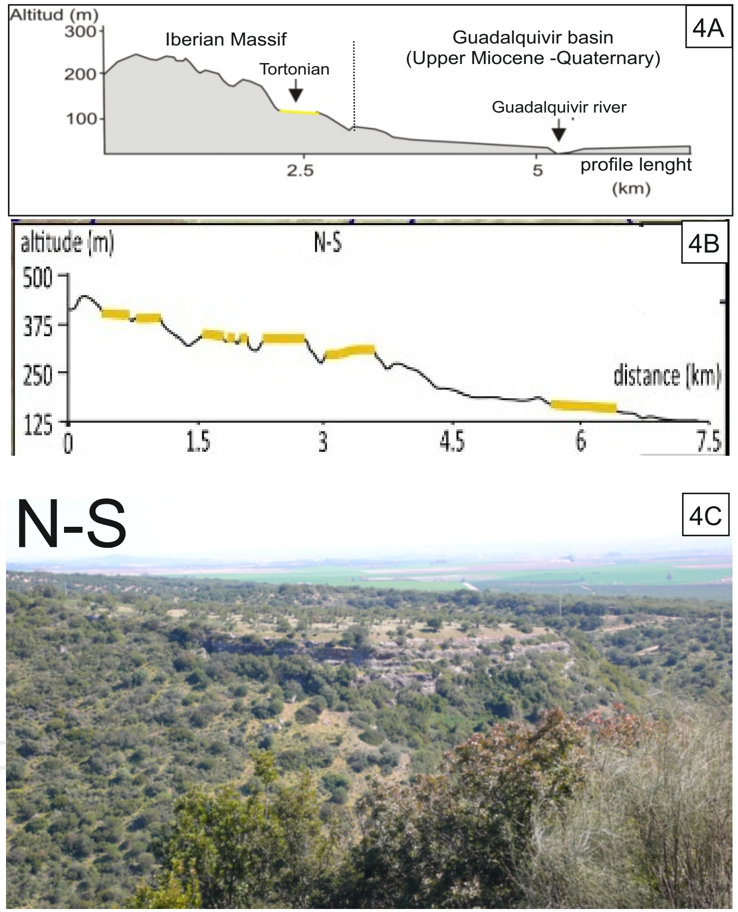


Fig.4. A&B Topographic profiles of the foreland escarpment (see location on Fig. 1). C). Neogene marine sediments on top of the Paleozoic rocks of the Ossa-Morena

Quantitative results(i)

Quantitative geomorphic indices have been calculated to constrain the time span of the recent tectonic activity (Fig.5):

-*Hipsometric curves and hipsometric integra*l, *HI* (Keller&Pinter, 2002): convex curves and HI values > 0.6 are related to recent relief rejuvenation.

-*Sinuosity of mountain fronts*, *Smf* (Bull and McFadden, 1977): 1.32 >Smf values>1.15 are related to tectonically active fronts.

-*Valley floor-to-height ratio, Vf* (Bull and McFadden, 1977) : Vf values < 1 are related to areas with active uplift.

-*Minimum bulk erosion, Ebulk* (Azañón et al., 2012): permits to compare amount of erosin along a river profile.

-SLK index (Pérez-Peña et al., 2009): high values indicate deviation from the expected equilibrium slope along the river profile.

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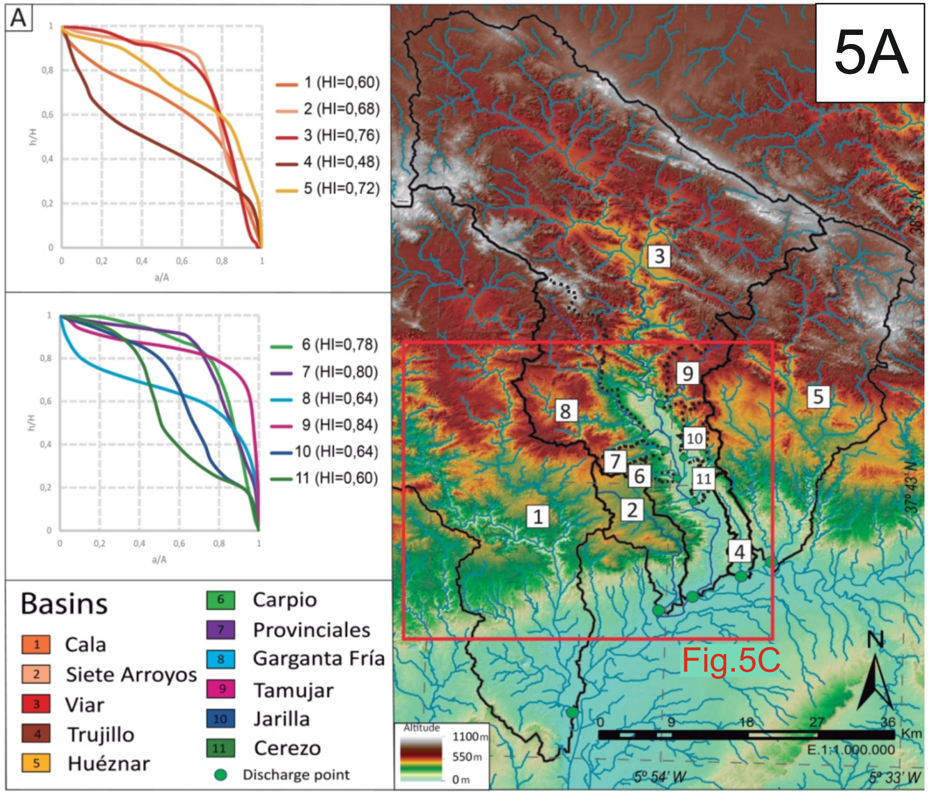
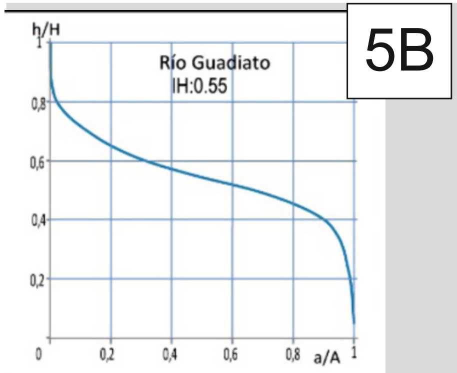




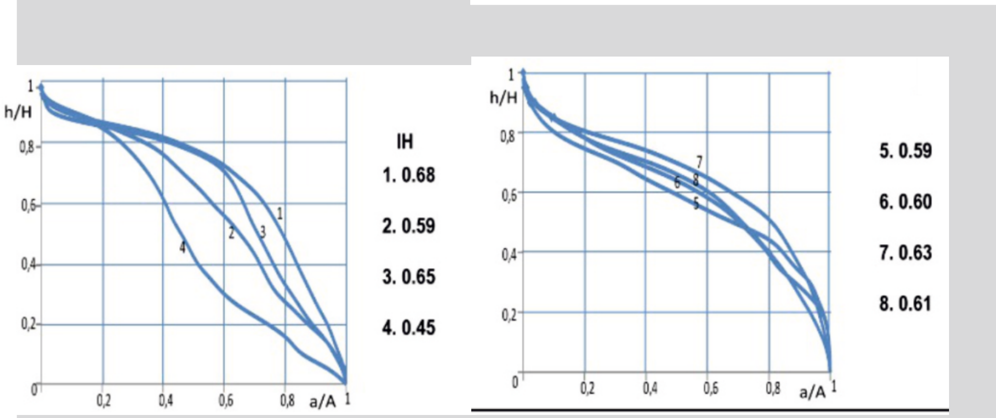
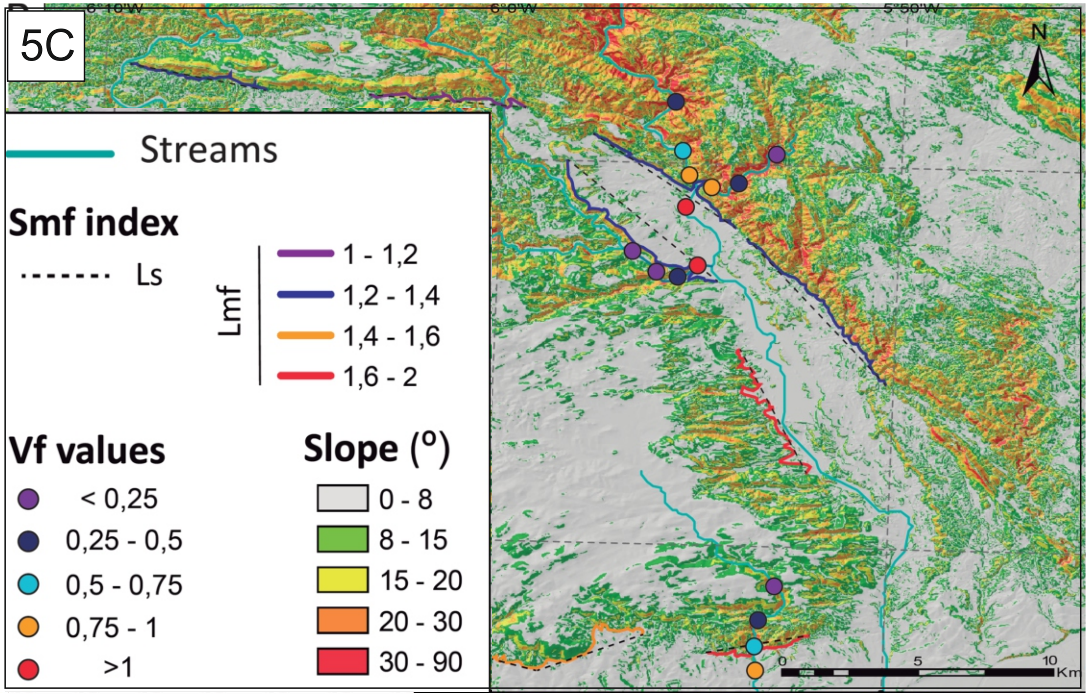
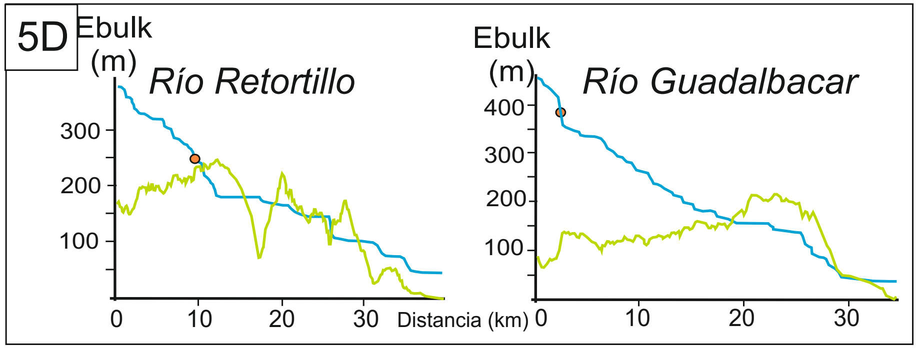
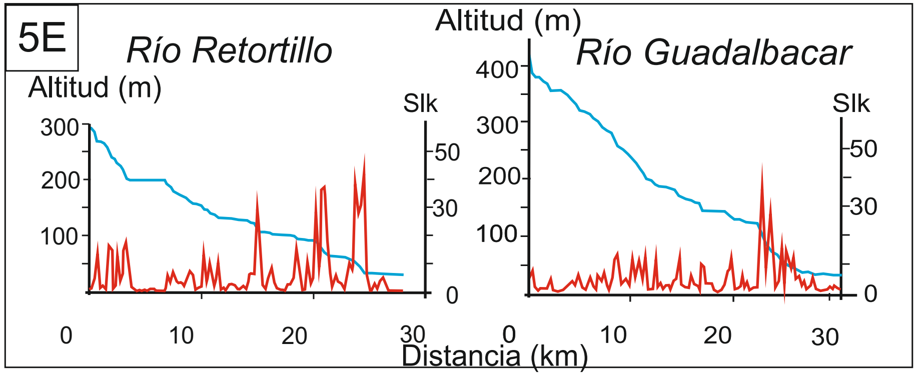


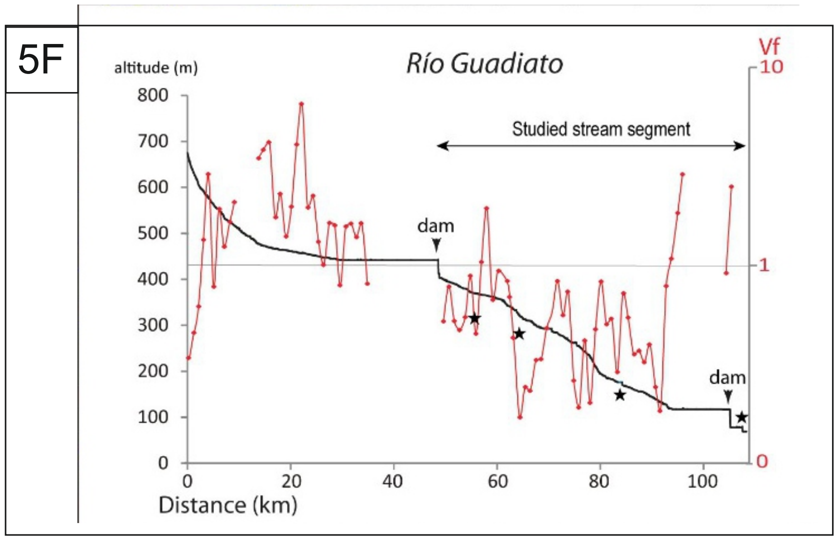
Fig 5. A) Hypsometric curves and HI for 11 drainage catchments in the Viar catchment area (see location in Fig. 1B), and B) in the Guadiato area (see location in Fig. 1B and 7A) .

Quantitative results(ii)









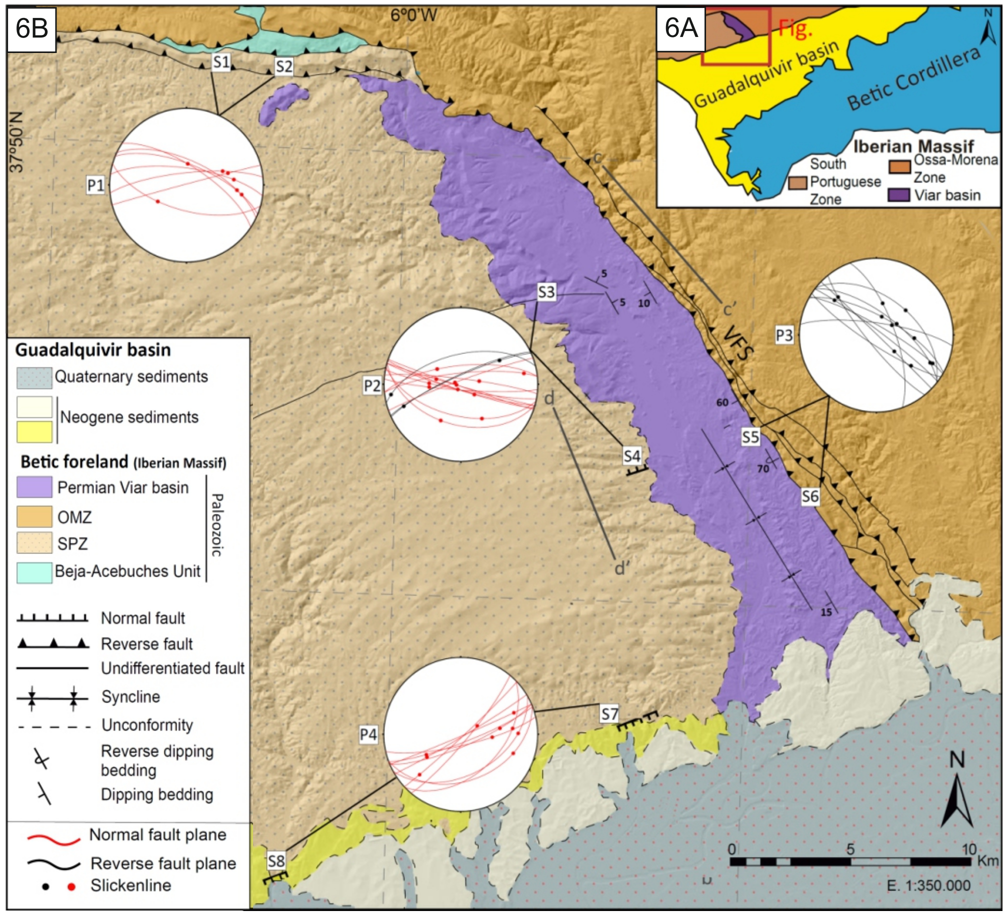
5C) Smf and slope map of the Viar catchment area (see location on Fig. 5A) showing the mountain front chosen segments; Smf values are shown by the gradation of colors in the Lmf line, Vf values are pointed by the color. 5D and E) Ebulk and Slk index , repectively, related to longitudinal profiles of the Retortillo and Guadalbarcar rivers, incised in the Iberian Massif escarpment (Fig.1B). 5F) Vf on the Guadiato long profile.

Structural analysis (i): Viar catchment/Puebla de los Infantes sector

Structures related to relieve rejuvenation:

a) **WSW-ENE** dominantly normal faults, with a variable lateral component, responsible for **NNW-SSE foreland relief segmentation**

b) **the Viar Fault**, recently reactivated as a left-lateral, reverse fault system, which has produced **WSW-ENE relief segmentation** localized in the current Viar catchment



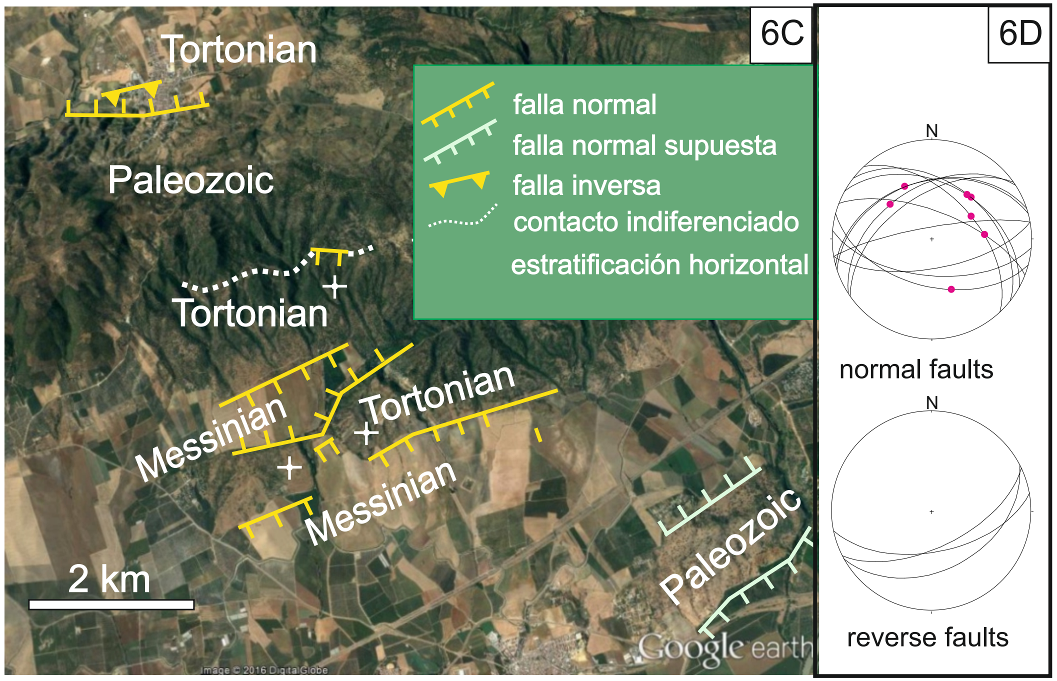


Fig 6. A) Location of Fig.6B in SW Iberia. B) Simplified geological map of the Permian Viar basin area with the location of the structural measurement stations (S1-8), resulting stereograms (P1-4) and topographic profiles of Fig. 3C&D. VFS, Viar fault system; OMZ, Ossa-Morena Zone; SPZ, South Portuguese Zone C) Faults in the Puebla de los Infantes sector (location on Fig. 1B). D) Stereograms of faults in Fig. 6C. VFS, Viar fault system; OMZ, Ossa-Morena Zone; SPZ, South Portuguese Zone.

Structural analysis (ii): Guadiato river sector

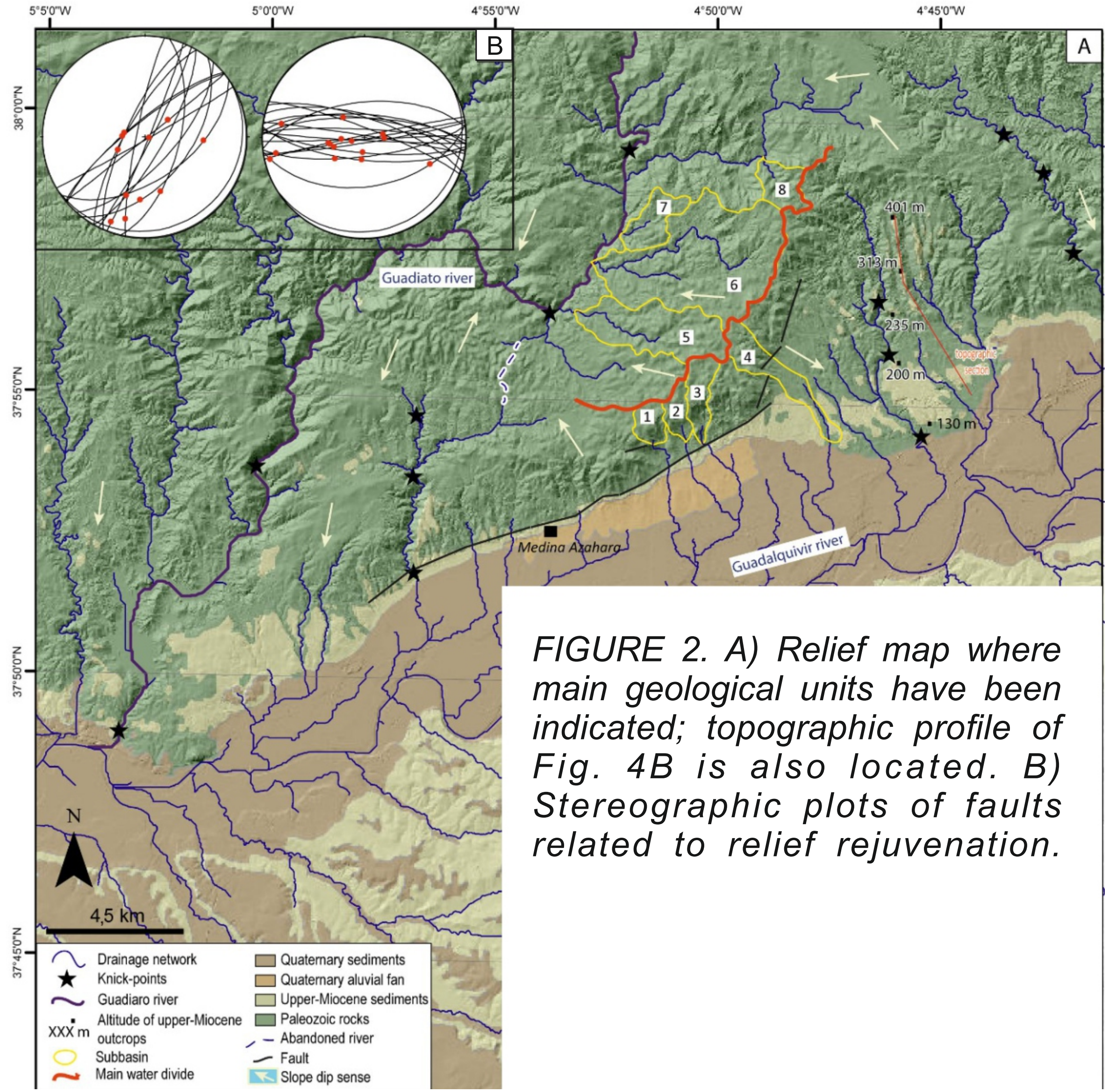


FIGURE 2. A) Relief map where main geological units have been indicated; topographic profile of Fig. 4B is also located. B) Stereographic plots of faults related to relief rejuvenation.

Structures related to relieve rejuvenation are distributed around two strikes:

a) W-E system: steeply dipping faults with a dominant dip-slip component (uplifting the northern block). A subordinate right-lateral slip is **frequently present**

b) SW-NE system: steeply dipping faults though slip-dip (uplifting the NW block) and right-lateral components are equally observed.

North of the Medina Azahara archaeological site (Fig.2A), escarpment-derived colluviums of debris facies can be observed, both pre- and post-dating the construction of the ancient city (abandoned and vandalised soon after 1036 A. C., López-Cuervo, 1983)

Discussion and conclusions

- Both qualitative and quantitative geomorphic results point to a Quaternary activity of faults, responsible for the relief rejuvenation of the Betics foreland in our study area

- The escarpment between the Iberian Massif and the Guadalquivir basin as well as the N-S relief segmentation of the Iberian Massif, are mainly related to oblique, right-lateral, normal faults. Conversely, the topographic drop between the Viar catchment and its NE range is related to the reactivation, as mainly reverse, left-lateral faults of the VFS.

- In the Guadiato river sector, the recent activity has additionally contributed to the recent NW-ward tilting of the foreland paleosurface in the Guadiato River lower course, assumed to be originally dipping toward the foreland basin.

- The SW-NE faults overall trend is in agreement with those faults expected to accommodate extension by flexural bending in the Betics forebulge. In this regards, normal faults with a dominant dip-slip component are frequent. Nevertheless, many of these structures are vertical or steeply dipping reverse faults suggesting that vertical extrusion prevails over extension. This fact suggests that current compression of the forebulge may occurred coeval with flexural bending.

- The right-lateral component of normal faults, combined with the reverse, left-lateral slip of the NW-SE VFS suggests that such compression would be oblique, slightly rotated clockwise with respect to the overall SW-NE faulting trend., which is in agreement with the far field vector orientation (between N99ºE and N109ºE) proposed in previous workfor the recent deformation of the Betics fold and thrust belt.