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Kinematics of the Torcal Shear Zone: Transpressional tectonics in a salient-recess transition at the northern Gibraltar Arc

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ABSTRACT

Complex strain patterns in the Gibraltar Arc derive from the interaction between the westward drift — and concomitant back-arc extension — of the arc hinterland (Alboran Domain) and the Europe–Africa convergence. In order to explore strain partitioning modes within the arc and the role played by large-scale oblique structures, we have studied the kinematics of the Torcal Shear Zone located at the northern branch of the Gibraltar Arc.

The Torcal Shear Zone is a 70 km-long, E–W brittle-ductile shear zone that underwent overall dextral transpression during the Late Miocene to Quaternary time. Within the Torcal Shear Zone strain is highly partitioned at multiple scales into shortening, oblique, extensional and strike-slip structures. Moreover, strain partitioning is heterogeneous along-strike giving rise to four distinct structural domains. In the central sector the strain is pure-shear dominated, although narrow sectors parallel to the shear walls are simple-shear dominated. A single N99°E–N109°E trending horizontal velocity vector ($\vec{V}$) could explain the kinematics of the entire central sector of the Torcal Shear Zone. Lateral domains have different strain patterns and are comparable to splay-dominated and thrust-dominated strike-slip fault tips.

The Torcal Shear Zone provokes the subvertical extrusion of the External Betics units against the Alboran Domain and a dextral deflection of the structural trend. Moreover, the estimated $\vec{V}$ points to the importance of the westward motion of the hinterland relative to the external wedge and fits well with the radial outward thrusting pattern identified in the arc.

1. Introduction

Map traces of orogenic belts describe a great variety of geometries that often result in a set of interconnected large-scale, curving trend lines (e.g. Marshak, 2004). Within the external wedges of orogens, studies carried out on a variety of natural cases together with analogue modelling have shown that the controls on these curving geometries are very different in nature. Variations in stress trajectories, predeformational thickness, indenter shape, tectonic transport direction patterns, and strength of detachment levels have been identified as the main controlling factors (Macedo and Marshack, 1999; Marshak, 2004). Furthermore, apparent similar geometries could be acquired by following very different strain paths (Hindle and Burkhard, 1998).

Map–view curves in fold-and-thrust belts develop either convex (salient) or concave (recess) to the foreland. Study cases have shown that transition zones between them (including the end points of Macedo and Marshak, 1999) correspond to continuous or discontinuous map-view inflexion zones in which strike-slip tectonics commonly occur. Examples of these are: the strike-slip fault zones between the Richardson Mountains and the Mackenzie salient (Mazzotti and Hyndman, 2002), the SW faulted border of the Western Alpine Arc (Collombet et al., 2002), and the strike-slip fault zones at both sides of the Sulaiman salient in Pakistan (Marshak, 2004). These strike-slip deforming zones trend oblique to the dominant structural grain and could be accompanied by a wide zone of distributed deformation, as is the case of the western end of the Himalayan Arc (Mohadjer et al, 2010).

From a kinematic perspective, transpressive shear zones could be expected as one of the most common cases in the lateral parts of salients given that they typically develop in oblique convergence settings. Apart from different sources of data, the study of these bands has progressively incorporated results from analogue (Casas et al., 2001; Leever et al., 2011; Schreurs and Colletta, 1998; Tikoff and Peterson, 1998) and analytical modelling (Fernández and Díaz-Azpiroz, 2009; Jones et al., 2004; Lin et al., 1998). In this regard, some works carried out on ductile transpressive shear zones have successfully compared natural strain markers with the finite strain ellipsoids produced by analytical models (Czeck and Hudleston, 2003; Fernández et al., 2013).

In the westernmost Mediterranean, the hinge zone of the Gibraltar Arc is a 300-km-long salient that ends at the apex of two recessing zones (Balanyá et al., 2007; Fig. 1). Salient-recess transitions are characterized in both cases by essentially brittle strike-slip dominated shear zones: the Torcal Shear Zone (TSZ) (Barcos et al., 2011; Díaz-Azpiroz et al., 2014) and the Jebha Fault Zone (Leblanc and Olivier, 1984).

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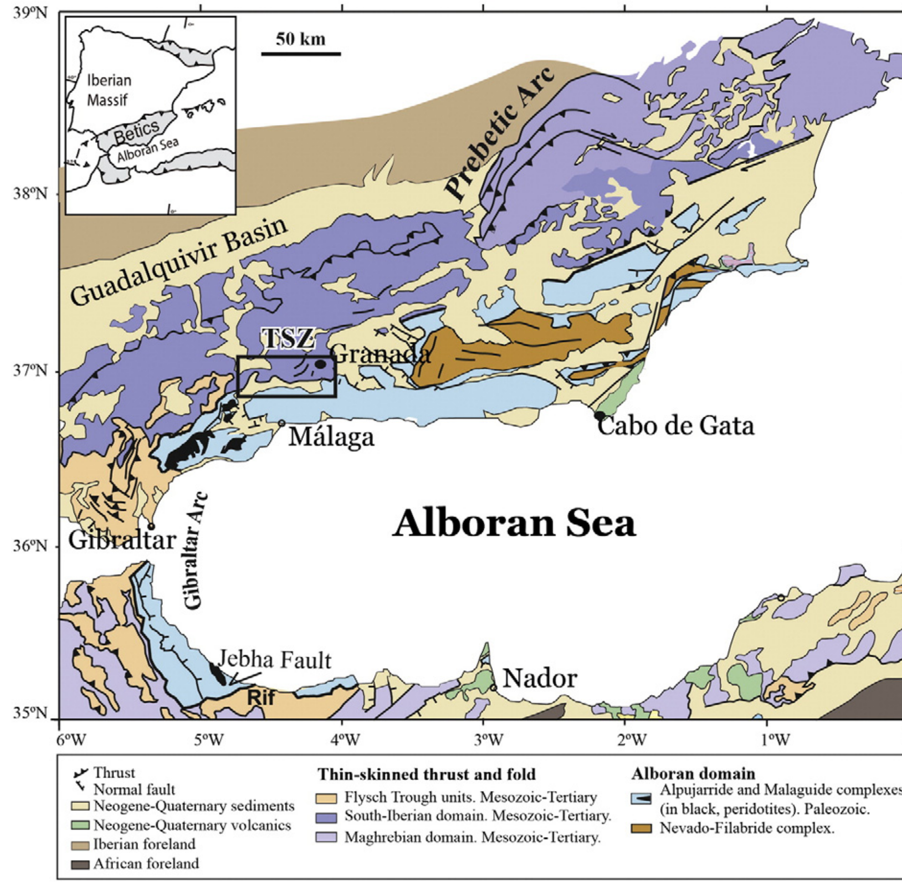

Fig. 1. Tectonic map of the main tectonic domains forming the Gibraltar Arc, modified from García-Dueñas et al. (1992) and Balanyá et al. (2007). Location of the Torcal Shear Zone is shown.

Kinematics of the central part of the TSZ has been recently studied by applying theoretical analytical models of general transpression (Díaz-Azpiroz et al., 2014), but a regionally integrated structural analysis of the complete TSZ has not been attempted yet. Moreover, theoretical models have not been applied out of the Torcal de Antequera massif within the central sector of the shear zone. As a consequence, the tectonic implications of the TSZ in terms of large-scale strain localization and its significance within the Gibraltar Arc kinematic frame remain unexplored. The present work offers a complete revision of the entire TSZ and its relationships with neighbouring areas, based on previous and new kinematic data together with the application of theoretical analytical models. We discuss: 1) the overall kinematics of the TSZ from an exhaustive inventory of coeval structures within the shear zone, including their lateral tip zones, 2) the changing strain partitioning modes along the TSZ as viewed from the application of an analytical model of oblique transpression, and 3) the kinematic role played by the TSZ in the context of a salient-recess transition within the Gibraltar Arc.

2. Tectonic setting

The Western Mediterranean Sea was formed during the Neogene as a back-arc basin related to the activity of the Western Mediterranean Subduction Zone (Faccenna et al., 2004). The Calabrian and Gibraltar arcs close the system to the East and to the West respectively.

The Betic and Rif chains build up the two branches of the Gibraltar Arc enclosing the Alboran back-arc basin (Comas et al., 1999). Although the internal zones of the arc (the Alboran Domain) were mostly built during the Paleogene (Azañón et al., 1997; Balanyá et al., 1997), the curved pattern of the Gibraltar Arc is a Neogene feature. The Arc formed by the westward motion of the Alboran Domain, thrusted during the Early to Middle Miocene onto two foreland domains: the South Iberian and Maghrebian domains that gave way to the Betic and Rif fold-and-thrust belts, respectively. In-between the Alboran Domain and the deformed forelands, there are tectonic slices of the so-called Flysch Complex (Luján et al., 2006), which contains very deep water sediments witnessing the existence of a Jurassic to Early Cretaceous oceanic lithosphere now subducted (Durand-Delga et al., 2000; Faccenna et al, 2004).

Different lithospheric mechanisms causing arc migration and coeval back-arc extension have been proposed, such as asymmetric lithosphere delamination (García-Dueñas et al., 1992), subduction slab retreat (Faccenna et al., 2004; Royden, 1993; Thiebot and Gutscher, 2006) and hybrid subduction–delamination models (Booth-Rea et al., 2007; Duggen et al., 2005).

The salient geometry of the hinge zone of the Gibraltar Arc is defined by diverse shortening structures that form the main structural grain (Balanyá et al., 2007): the Alboran Domain outer tectonic boundary, the folds and thrusts of the deformed foreland units and the Flysch Complex, and the late Miocene folds within the emerged Alboran Domain. The northern end point of the salient could be approximately placed in the apex of the adjacent recess zones close to the 4°30′W meridian (Fig. 1), i.e. along the Torcal Shear Zone (Barcos et al., 2011; Díaz-Azpiroz et al., 2014) that involves rocks belonging to the innermost South Iberian Domain. Actually, the southern TSZ wall forms the current boundary between the South Iberian units and the Alboran Domain.

The South Iberian Domain is composed in the studied area by three main rock groups: a) marls with evaporites, limestones and dolostones of Triassic age, b) dolostones, oolitic and nodular limestones (Lower to Upper Jurassic), and c) white and red marly limestones (Lower