WSW-ENE extension in Mallorca, key for integrating the Balearic Promontory in the Miocene tectonic evolution of the western Mediterranean

Extensión WSW-ENE en Mallorca, deformación clave para integrar el Promontorio Balear en la evolución tectónica del Mediterráneo occidental

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Abstract: Mallorca forms part of the external thrust belt of the Betics. However, presently, it is surrounded by thin crust of the Valencia Trough and the Algero-balearic basin and is disconnected from the Internal Betic domains. The main tectonic structures described in the island correspond to thrusts that structured the Tramuntana and Llevant Serres during the Late Oligocene to Middle Miocene. Meanwhile, normal faults with NW-SE transport determined the development of Serravallian to Tortonian basins. Here we present a preliminary tectonic model for Mallorca after revising the contacts between supposed thrusts in Tramuntana and Serres de Llevant. This analysis shows the existence of important low-angle extensional faults with WSW-ENE transport, older than the high-angle NW-SE directed extensional system. Extensional deformation is more pervasive towards the Serres de Llevant where normal faults represent most of the contacts between units. This extensional gradient is favored by ENE-WSW strike-slip transfer faults, and probably, by the faults that bound the southeastern margin of Mallorca. These faults produced the extensional collapse of Mallorca during the Late Langhian-Serravallian, dismembering the external from the internal zones, which now occupy a more westerly position in the core of the Betics.

Key words: Betics, Mallorca, extension, transfer faults.

Resumen: *Mallorca forma parte de las zonas externas Béticas, sin embargo, se encuentra rodeada de corteza adelgazada del Golfo de Valencia y de la Cuenca Argelino-Balear, desconectada de los dominios Béticos internos. La mayor parte de las fallas descritas en la isla de Mallorca son cabalgamientos que estructuraron las sierras de Tramuntana y de Llevant desde el Oligoceno superior hasta el Mioceno medio. Mientras que fallas extensionales de alto ángulo con transporte NW-SE han configurado la geometría de cuencas del Serravalliense y Mioceno superior. Aquí presentamos un modelo preliminar para la evolución tectónica de Mallorca después de haber revisado algunos de los contactos entre supuestos cabalgamientos en las sierras de Tramuntana y Llevant. Este análisis muestra la existencia de fallas normales de bajo ángulo con transporte WSW-ENE previas al sistema extensional con transporte NW-SE. La penetratividad de estas estructuras aumenta hacia las Serres de Llevant dónde fallas normales forman la mayor parte de los contactos tectónicos. Este gradiente extensional está compartimentado por fallas transfer de orientación ENE-WSW, y probablemente, por las fallas que configuran el borde SE de la isla. Estas fallas produjeron el colapso extensional WSW-ENE de Mallorca durante el Langhiense superior-Serravalliense, desmembrando las zonas externas de las zonas internas, que actualmente ocupan posiciones más occidentales en el núcleo de las Béticas.*

Palabras clave: *Béticas, Mallorca, extensión, fallas transfer.*

INTRODUCTION

Mallorca represents a key area to understand the tectonic evolution of the western Mediterranean. It has been classically interpreted to form part of the external Betic thrust belt; however it lacks the Internal Betic hinterland backstop region, being surrounded by highly extended domains, including the oceanic Algero-Balearic basin to the southeast (e.g. Sàbat et al., 2011). Most tectonic models explaining the evolution of the western Mediterranean fail to integrate the geology of Mallorca that requires the existence of a backstop domain to the southeast of it during the Burdigalian-Langhian, main period of WNW-directed thrusting in the island (e.g. Gelabert, 1998). Here we propose a preliminary tectonic model for the evolution of Mallorca after revising the contacts between tectonic units in the Serres de Tramuntana and Llevant and evaluating the importance of WSW-ENE directed extension during the Late Langhian-Serravallian.

EXTENSIONAL STRUCTURES IN MALLORCA

A close evaluation of the contacts between thrusted units in the Sierras de Tramuntana and Llevant shows clear extensional deformation (Figs. 1, 2, 3). Two extensional systems have been observed, a younger one formed by high-angle faults with mostly SE-directed hanging-wall transport, and an older system with ENE-WSW directed transport. These data are coincident with paleostress analysis (Céspedes et al., 2001). The older extensional faults are characterized by meter to decametre thick cataclastic shear zones with WSW-ENE slicken lines that cut through the previous contractive structures, like folds and thrusts with WNW-directed transport. These shear zones are frequently tilted by younger faults with the same kinematics, indicating out-of-sequence faulting (Fig. 3C). The shear zones show abundant porphyroclasts from cartographic to outcrop scale within fault breccias with foliated cataclasites and extensional S-C´structures (Fig. 3A-D).

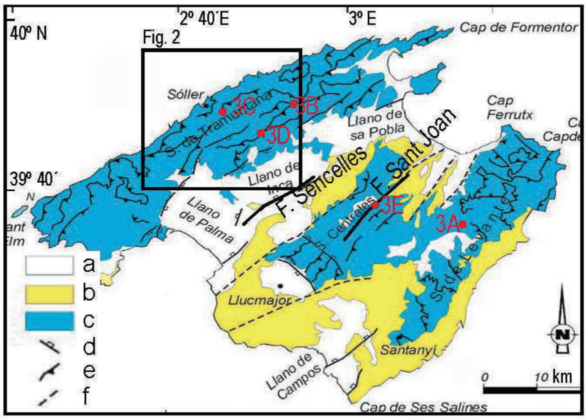

FIGURE 1. *Geological sketch of Mallorca with the location of Fig. 2 and photos in Fig. 3. The Sant Joan and Sencelles transfer faults are shown too: a) Quaternary, b) Late Miocene, c) Mesozoic-Early Miocene, d) normal fault, e) supposed thrust, f) inferred fault Modified from Gelabert, 1998.*

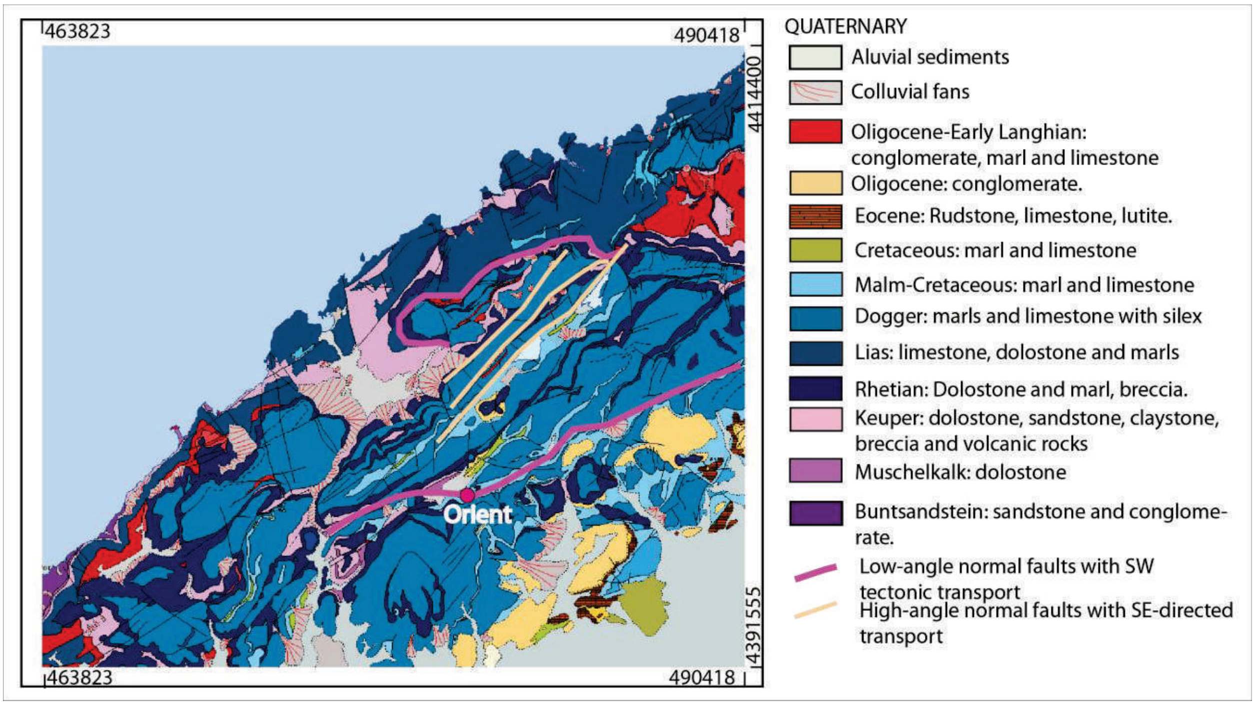

FIGURE 2. *Geological map of the central sector (Sóller) of Serra de Tramuntana showing low-angle normal faults cutting through the nappe stack. See Fig. 1 for the location of this map. Modified from ITGE, 1991.*

At cartographic scale the shear zones cut down into the thrust pile omitting different thrust sheets towards the movement sense. For example, the Orient detachment to the south of Serra de Tramuntana omits up to three thrust sheets in the direction of transport. This structure dips approximately 30º towards the SE and shows tectonic transport towards the SW, thus having dextral transtensive kinematics (See Orient, Fig. 2). The Orient detachment probably roots in a SE-dipping reflector observed in seismic reflection line 10 of G.E.S.A at 1.5 s TWT under the central region of Mallorca (Gelabert, 1998). The extensional detachments show ramp-flat type geometries typical of structures that cut through a heterogeneous rheological pile with alternating carbonate and pelitic rocks, stacked during the previous thrusting stage (Booth-Rea et al., 2004). This results in multiple extensional detachments developed in the most plastic materials, corresponding to Triassic red-beds and gypsum or Late Jurassic to Cretaceous pelagic series. These ENE-WSW transport faults affect Burdigalian marls and turbidites and are partly sealed by Serravallian-early Tortonian lacustrine sediments.

Strike-slip faults with NE-SW orientation also occur in Mallorca, for example the sinistral Sencelles fault that bounds the south of the Inca basin (Mas-Gornals et al., 2014) or the dextral Sant Joan fault that cuts through the Central ranges of Mallorca (Fig. 1). These faults show the same orientation but contrary kinematics and bound sharply several basins and the borders of the Alcùdia and Palma bays in Mallorca. This is manifested by the isopachs of Late Miocene to Quaternary materials of the island (e.g. Sabat et al., 2011), indicating that these strike-slip faults have continued their activity during the Late Miocene and Pliocene.

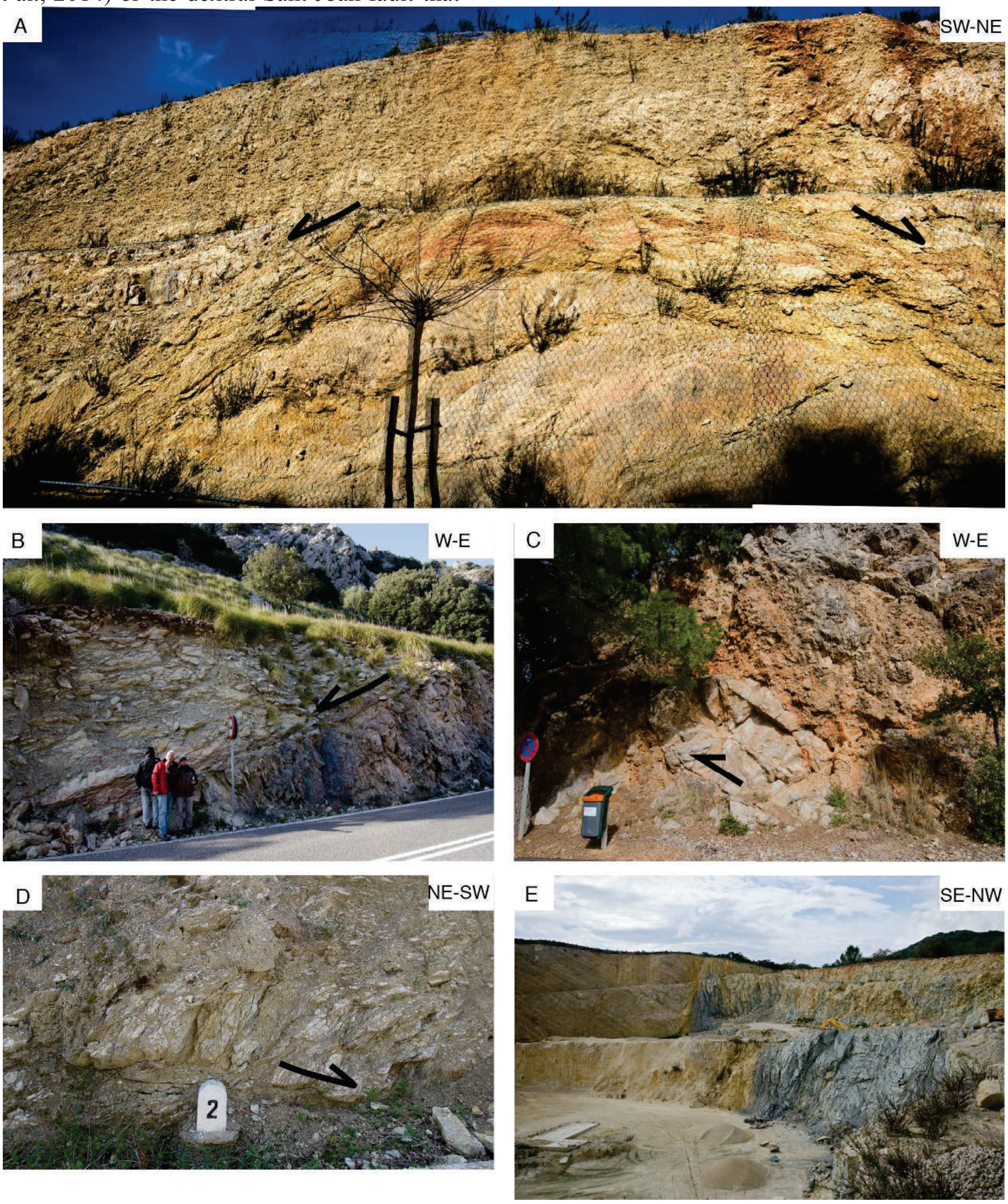

FIGURE 3. *Outcrop photographs of extensional structures in Mallorca, located in Figure 1. A) Low-angle extensional deformation in Serres de Llevant, near Manacor, showing cataclasis and faults with both NE and SW tectonic transport. B) SW-directed low-angle fault affecting upper Jurassic pelagic sediments. C) Tilted breccias at the base of an extensional detachment near the locality of Sóller. Slicken lines in these fault rocks indicate westward tectonic transport. D) Fault rock with brittle extensional shears in the Orient detachment. Tectonic transport towards the SW. E) Sant Joan dextral-reverse strike-slip fault.*

DISCUSSION

Low-angle normal faults with NE-SW transport in Mallorca have thinned the previous thrust stack in both the Tramuntana and Llevant sierras after the Early Langhian (14.4 Ma), age of the youngest sediments cut by thrust surfaces. NE-SW extension is achieved by normal faults that occur at all scales, from faults with metric displacements to large detachments like the Orient low-angle normal fault that omit several thrust sheets in the transport direction. Extensional deformation in these faults is characterised by producing pervasive cataclasis in a large area around the faults, contrary to the thrusts that show relatively thin fault zones. These faults are responsible for the extensional collapse of Majorca during the middle Miocene and must be related to the SW-NE middle to late Miocene opening of the Algero-Balearic basin (Mauffret, 2006; Booth-Rea et al., 2007). During the late Miocene, extension in Mallorca was dominated by normal faults producing NW-SE extension that have influenced the present topography of Mallorca (e.g. Sàbat et al., 2011).

The presence of strike-slip faults with the same orientation but with contrary kinematics is a common characteristic of extensional transfer faults that are also parallel to the main extensional direction (e.g. Giaconia et al., 2014). This, together with the clear influence these strike-slip faults have in the sediment isopachs of Mallorca suggests that they represent extensional transfer faults that together with other ones like the Emile Baudot excarpment, permitted heterogeneous extension between the Tramuntana and Llevant sierras, and also between these onshore regions and the Algero-Balearic basin further south.

WSW-directed extension contributed to the isolation of Mallorca from its Betic hinterland, represented by the Alboran crustal domain, which was displaced further to the southwest by the opening of the Algero-Balearic oceanic basin. Tearing of the Iberian lithospheric slab under the southern border of the Balearic Islands probably drove this extension during the middle Miocene. This rupture propagated towards the WSW reaching the SE Betics in the Tortonian (Mancilla et al., 2015). This work shows the necessity to further analyse the geometry and kinematics of brittle deformation in Mallorca, where many contacts interpreted as thrusts are probably low-angle normal faults that have cut and omitted the previous thrust surfaces.

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