Sociedad Geológica de España

GEOGACETA, 57, 2015

Structure and kinematics of Subbetic and related mélange-like units NW of Ronda Basin (Western Betics): evidences for a transpressional structural high in the frontal thrust-and-fold belt

Estructura y cinemática del Subbetico y unidades tipo* mélange *al NW de la Cuenca de Ronda (Béticas Occidentales): evidencias de un alto estructural transpresivo en el frente del cinturón de pliegues y cabalgamientos

Alejandro Jiménez-Bonilla, Inmaculada Expósito, Juan Carlos Balanyá, Leticia Barcos and Manuel Díaz-Azpiroz

Departamento de Sistemas Físicos, Quimicos y Naturales, Universidad Pablo de Olavide, cra. de Utrera km 1, 41013 Sevilla, Spain.
ajimbon@upo.es, iexpram@upo.es, jcbalrou@upo.es, lbarmur@upo.es, mdiaazp@upo.es.

ABSTRACT

The Olistostromic Unit has been interpreted as a "mélange" deposited in the inner Guadalquivir basin, due to the uplift of the orogenic front. The NW boundary of the Ronda Basin is made up of discontinuous competent blocks surrounded by gypsy mudstones, somehow resembling the Olistostromic Unit. A detailed kinematic analysis has shown that this boundary constitutes a WSW-ENE structural high, post-Tortonian in age, where the strain is partitioned into: (1) WSW-ENE dextral strike-slip faults, (2) SW-NE shortening structures and (3) NW-SE normal faults. The main dextral fault zone is relieved by NW-SE oblique segments, dominated by either stretching or shortening structures, which could be interpreted as releasing and restraining bends, respectively. As a whole, the zone is interpreted as a transpressive band developed in the frontal part of the thrust-and-fold belt proper, the "Olistostromic Unit" probably cropping out toward the N.

Key-words: *Transpression, Olistostromic Unit, fold-and-thrust belt proper, post-Tortonian.*

RESUMEN

La Unidad Olistostrómica es interpretada como una "mélange" depositada en la parte interna de la cuenca del Guadalquivir durante el levantamiento del frente montañoso. El borde NW de la Cuenca de Ronda, al igual que la Unidad Olistostrómica, está constituido por bloques competentes discontinuos rodeados por rocas arcilloso-yesíferas. Sin embargo, un análisis cinemático pormenorizado muestra que este límite constituye un alto estructural post-Tortoniense donde la deformación está repartida en: (1) fallas de salto en dirección dextras WSW-ENE, (2) estructuras de acortamiento de dirección SW-NE y (3) fallas normales NW-SE. La principal zona de falla dextra está relevada por segmentos oblicuos NW-SE, dominados por estructuras bien de estiramiento, bien de acortamiento, interpretados como escalones extensivos o compresivos respectivamente. Este límite es así interpretado como una banda transpresiva en el frente del cinturón de pliegues y cabalgamientos, encontrándose la Unidad Olistostrómica probablemente hacia el N.

Palabras clave: *Transpresión, cinturón de pliegues y cabalgamientos definido, post-Tortoniense.*

Geogaceta, 57 (2015), 27-30.
ISSN (versión impresa): 0213-683X
ISSN (Internet): 2173-6545

Fecha de recepción: 1 de julio de 2014
Fecha de revisión: 22 de octubre de 2014
Fecha de aceptación: 28 de noviembre de 2014

Introduction

In the Betics, the so-called "Olistostromic Unit" (Rodríguez-Fernández *et al.*, 2013 and references therein) has been interpreted as a mélange composed of scattered competent rocks fragments surrounded by clay-gypsum matrix which represents the Langhian-Lower Serravallian syn-orogenic infill of the Guadalquivir basin. The viscous rheology of both the Olistostromic Unit and the Triassic rocks has been proved to control extensional processes (post-Serravallian) in the Central Betics, resulting in a current tectonic breccia appearance (Rodríguez-Fernández *et al.*, 2013 and references therein). Similar formations have been described in the frontal part of other Alpine external orogenic zones acting as detachment levels during both contractional and extensional events (Festa *et al.*, 2010).

This work is carried out in the external Western Betics where both extensional and shortening deformation have been active at least up to Messinian times (Jiménez-Bonilla *et al.*, 2011, 2012).

We present new structural and kinematic data from a deformed band characterized by discontinuous competent rock units surrounded by plastic formations, hereafter referred to as "mélange-like units", interpreted in previous works as part of the "Olistostromic Unit" (Rodríguez-Fernández *et al.*, 2013). The study area is located between the inner part of the Guadalquivir foreland basin and the Betic fold-and-thrust belt, and forms the NW border of the intermontane Ronda Basin. Specifically, we aim to (1) characterize the geometry and the kinematics of the post-Tortonian structures involved in the NW boundary of the Ronda Basin, (2) precise the limit between the foreland basin and the fold-and-thrust belt and (3) explain the origin of oblique structures located in this boundary.

Copyright© 2015 Sociedad Geológica de España / www.geogaceta.com

Tectonic setting

The Betics build the northern Gibraltar Arc and formed by the Neogene collision between the hinterland (Alboran Domain) and the South Iberian paleomargin (Fig. 1A).

In the Western Betics (Fig. 1A) the Ronda Basin is an intermontane basin originated by crustal extension subparallel to the trend of shortening structures and infilled by gently deformed Upper-Miocene sediments (Jiménez-Bonilla *et al*., 2011, 2012) (Fig. 1B). The landscape in the Ronda Basin area is mainly controlled by late kilometer-scale shortening structures Upper-Miocene in age, where the main sierras (up to 1,500 m) coincide with NE-SW antiforms cored by calcareous rocks of Subbetic Units (Jiménez-Bonilla *et al*., 2011, 2012). This structural and topographic high is interrupted to the SW by the Colmenar Fault (Luján *et al*., 2000) and to the NE by the Peñarrubia Almargen Transverse Zone (ZTPA) (Fig. 1B).

The Ronda Basin is located in the fold-and-thrust belt, although it is limited to the NW by a structural high that develops on a transitional band located between the fold-and-thrust belt proper and the Guadalquivir foreland basin (Figs. 1A and B).

In this band, the main sierras, which are usually related to shortening structures, are mainly constituted by limestones and marls attributed to Middle Subbetic units (Jurassic to Cretaceous) (Martín-Algarra, 1987). These sierras are mostly surrounded by evaporitic and detrital units comparable to South-Iberian Triassic formations defined east of this sector (Pérez-Valera and Pérez-López, 2003). The Flyschs Units usually crop out in synforms. There are also some unconformable Tortonian-Messinian deposits partially deformed (Fig. 1B).

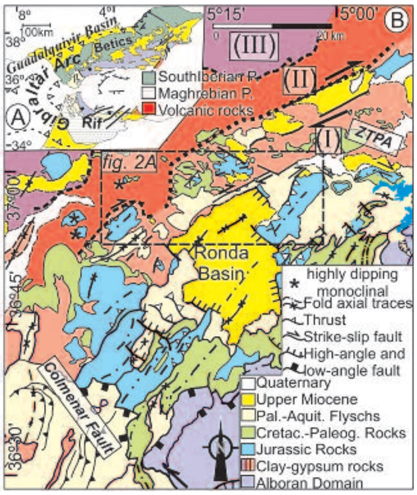

Fig. 1.- Geological map of the Gibraltar Arc (A) and structural map of the Ronda Basin area (B). Meaning of I, II and III discussed in the text.

Fig. 1.- Mapa geológico del Arco de Gibraltar (A) y estructural del área de la Cuenca de Ronda (B). Significado de I, II y III discutido en texto.

Structures of the NW boundary

To undertake the structural and kinematic characterization of the post-Tortonian structures of the Ronda Basin NW boundary, we have selected two representative sectors. Each of them is characterized by its tectonic and lithostratigraphic continuity: the Sierra de Líjar Sector, to the west, and the Olvera-Algámitas Sector, to the east (Fig. 2A).

Sierra de Líjar Sector

In the Sierra de Líjar Sector (Fig. 2B), the structural trend is mainly controlled by kilometer-scale NE-SW box folds. Their steep limbs include Lower Tortonian sediments of the Ronda Basin (Fig. 2A). Flyschs Units and Subbetic Units crop out in synform and antiform cores, respectively (Fig. 2B). Inside the Flyschs Units, a previous map-scale imbricate stack is deformed by the NE-SW folds and later faults (Fig. 2B).

The fold axial trace of the Líjar antiform (Fig. 2B) trends NE along ~7 km. In its hinge zone, 18 km² of Jurassic dolostones crop out, which compose a topographic range with a flat summit at 1,000 m (Fig. 2B). Both its NW and SE limbs are cut by kilometer-scale faults, trending subparallel to the fold axial trace (Figs. 2B, G). Their dip angles vary between 50° and 90°, being toward the NW in faults cutting the SE limb and toward the SE in those located on the NW limb (Figs. 2D, G). The whole system depicts a pop-up structure with a gentle NW vergence (Fig. 2D). The majority of the shear-sense criteria (calcite slikenfibres on the fault surface) with pitch angles between 0° and 50° indicate an important dextral strike-slip component. The reverse slip component contributes to the upthrow of the hinge zone block (Figs. 2B and G). NW-SE high-angle normal faults are widely represented in this sector. Most of them are 0.5 to 2.5 km long and displace the reverse-dextral faults and the antiformal axial fold trace (Figs. 2B and H).

Olvera-Algámitas Sector

The most remarkable feature in this sector is a WSW-ENE, ca. 15 km long brittle deformation zone (Olvera Fault Zone, OFZ), (Figs. 2A and C). This tectonic lineament is subparallel to the current NW limit of the Ronda Basin. The OFZ is bounded to the S by a N060ºE dextral strike-slip fault steeply dipping to the north (Figs. 2C and F). Within this deformation band there is a set of aligned Jurassic limestone blocks smaller than 200 m² which are limited by high-angle strike-slip faults, either sub parallel or oblique to the OFZ (N010ºE-N070ºE; Fig 2I). Shear-sense criteria suggest a dominant dextral strike-slip component (slickenlines with pitch angles around 20° and systematic subvertical extensional N125ºE joints, Fig. 2I). The dip-slip component of this fault zone is congruent with the uplift of the NW block (Fig. 2C).

The southern block of the OFZ is mainly composed by Flyschs Units, which are folded up by NE-SW map-scale folds that form a continuous fold train to the NE of the Ronda Basin (Figs. 2A and C).

The northern block of the OFZ is composed by Middle Subbetic rocks outcrops, surrounded by gypsum and clay-rich rocks. The structural trend in this sector is controlled by SW-NE reverse faults and kilometer-scale folds. The main structure is the Sierra del Tablón antiform, a NNW-vergent fold that trends N072ºE on average along ~6 km. The forelimb of the Tablón antiform dips ~ 70° to the NNW within the Jurassic sequence. Although the NW limb is well preserved, toward the W and SW this antiform is partially disrupted by multiple tectonic surfaces that bring Jurassic limestones into contact with Triassic rocks (Fig. 2C). These SW-NE folds are also interrupted by two sets of NW-SE structures: (i) To the E of the Olvera-Algámitas sector, NW-SE to NNW-SSE reverse faults cut the Tablón antiform trace at its eastern end (Fig. 2C). The main structure is a N155ºE thrust, 30º-60º W-dipping, which even affects Messinian rocks (Figs. 2A, C). (ii) To the W of the Olvera-Algámitas sector (near Harinas peak, Fig. 2A), high-angle NW-SE faults are the limits between either the Jurassic or Cretaceous rocks and the surrounding gypsum and clay-rich outcrops (Figs. 2A and C). Shear-sense criteria together with faults geometry show a dominant normal-sinistral faulting, although dextral strike-slip and reverse components have been locally observed (Fig. 2J).

Related to the end of some Subbetic outcrops, there are low-angle normal faults grouped in NE-SW and NW-SE striking sets, both detached in Keuper levels (arrows in Figs. 2A– C).

Discussion

NE-SW folds and reverse faults together with dextral strike-slip structures define as a whole a N060°E trending structural high which separates the Guadalquivir foreland basin from the Ronda Basin. This structural high comprises ranges up to 1.100 m and extends from the Sierra de Líjar to the Sierra del Tablón.

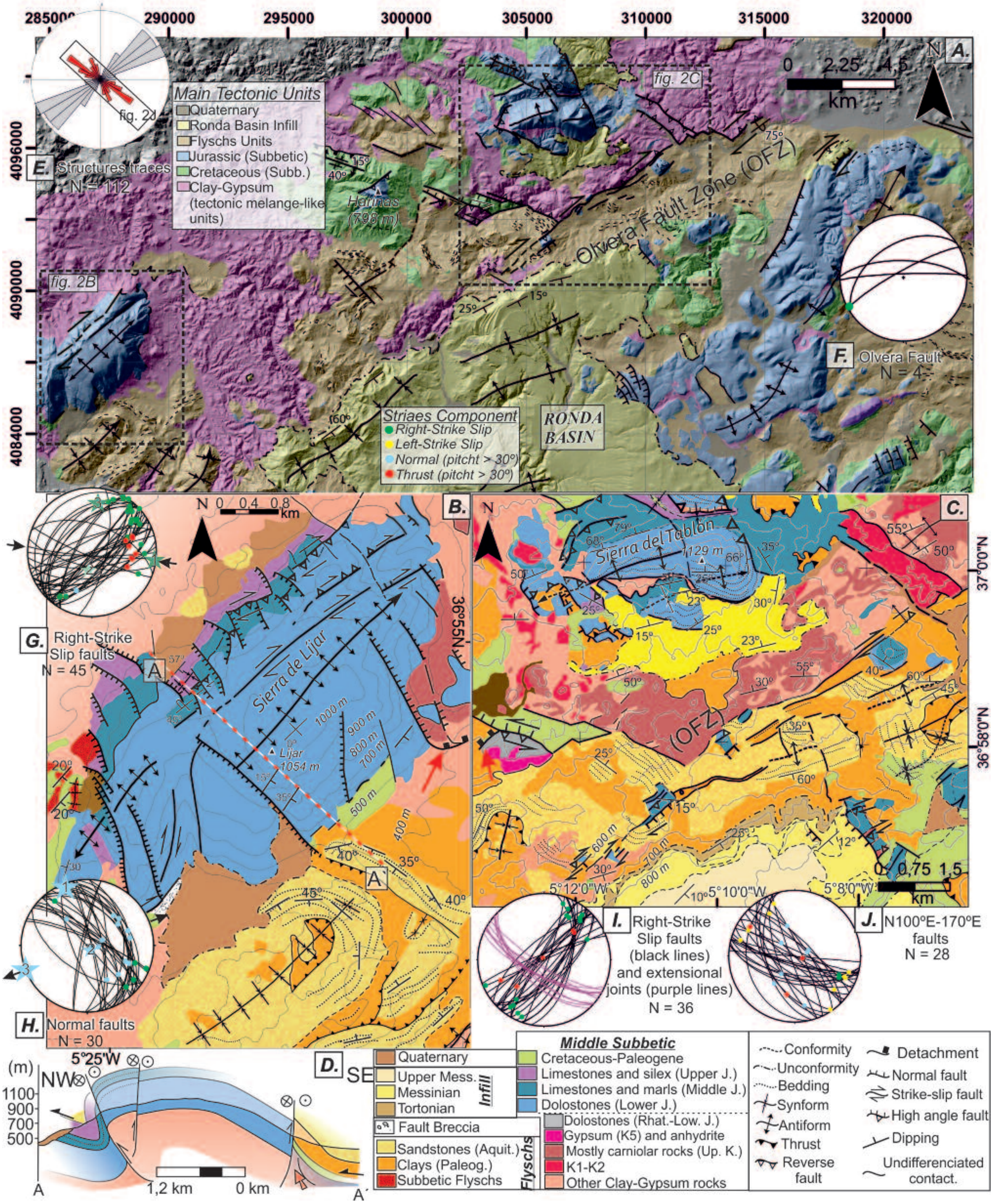

Fig. 2.- A) Structural map of the NW boundary of the Ronda Basin. B) and C) Geological maps of Sierra de Líjar sector and Olvera-Algámitas sector, respectively. D) Geological cross-section of Sierra de Líjar sector. E), F), G), H), I) and J) Stereoplots.

Fig. 2.- A) Mapa estructural del Borde NW de la Cuenca de Ronda. B) y C) Mapas geológicos del sector de la Sierra de Líjar y del sector Olvera-Algámitas, respectivamente. D) Corte geológico del sector Sierra de Líjar. E), F), G), H), I) y J) Estereogramas.

The structural association that develops in this band permits us to interpret it as a dextral transpressive zone where strain is partitioned between SW-NE folds and reverse faults structures and mainly right lateral stike-slip faults. Additionally, NW-SE normal faults accommodate extension parallel to the main structural trend. The fold train of the Líjar sector deforms the Tortonian infill of the Ronda Basin as well as the thrust detachment and the inner structure of the Flyschs Units (Figs. 2A and B), Lower to Middle Miocene in age (Luján *et al.*, 2000). In the Olvera-Algámitas sector, the structures (OFZ, kilometric folds and NW-SE reverse faults) also affect Messinian sediments (Martín-Algarra, 1987; Fig. 2C). Therefore, this band must have been active at least up to Messinian times.

The boundary between the Líjar and Olvera-Algámitas sectors can be located along the NW-SE normal-sinistral faults (near Harinas peak, Fig. 2A), where the OFZ is relieved to the west by the dextral strike-slip system of the Sierra de Líjar Sector. These NW-SE normal-sinistral oblique faults could be thus interpreted as the result of a releasing bend between two strike-slip segments (Barka *et al.*, 1988). The variable slickenline direction measured on these NW-SE normal-left-strike-slip faults could indicate some scape tectonics due to the rheology of the involved rocks.

In a similar way, the NNW-SSE and NW-SE reverse faults of the Sierra del Tablón, subperpendicular to the main shortening structures of the Ronda Basin area, (Jiménez-Bonilla *et al.*, 2011, 2012), could be related to a restraining bend between the OFZ and another studied WSW-ENE right lateral fault zone post-Tortonian in age located to the NE (Fig. 1B).

Summarizing, this structural high records an important post-Tortonian uplift, accommodated by the main structural elements of the area, which controlled the entire NW Ronda Basin boundary

In order to constrain the limit of the Olistostromic Unit, we have defined three provinces paying attention to their structural and/or lithological features: (1) The Zone I, which includes the NW boundary of the Ronda Basin (Figs. 1B and 2A) is affected by post-Tortonian structural associations whose trend and age are broadly similar to those described in the fold-and-thrust belt proper (Jiménez-Bonilla *et al.*, 2011, 2012). However, the transpressive tectonics developed in the Zone I, in conjunction with the contrasting competence of the involved rocks, resulted in the segmentation of the competent rock units that now appear surrounded by widespread gypsum and clay-rich outcrops. These associations include kilometer fold trains in structural continuity with those of the SW and NE boundaries of the Ronda Basin. This structural (and also lithoestratigraphic) connection allows us to interpret the Zone I, unlike previous works (Rodríguez-Fernández *et al.*, 2013 and references therein), as part of the fold-and-thrust belt proper. proper. (2) The Zone II (Fig. 1B) where most of the outcropping rocks are form by gypsum and clay-rich formations (mostly tectonically brecciated) of the Triassic sequence (Pérez-Valera *et al.,* 2003). The rest of outcrops are made up of Jurassic and Cretaceous rocks displaying a highly dipping monoclinal structure (Fig. 1B). These features make difficult to discern if Zone II could belong to the Langhian Olistostromic Unit (Rodríguez-Fernández *et al.*, 2013 and references therein). (3) In the Zone III Jurassic outcrops are surrounded by Middle Miocene sediments, which could represent the matrix of the Olistostromic Unit (Fig. 1B), being this zone therefore attributable to the Guadalquivir basin synorogenic infill.

In any case, the progressive advance of the deformation front may lead to the accretion of the most internal foreland infill, i.e. the Olistostromic Unit, to the fold-and thrust-belt as a tectonic mélange. This strong deformation makes difficult to establish the tectonic limit between the fold-and-thrust belt proper and the foreland basin.

The huge extension of Triassic rocks in the Zones II and III could be explained by either (or even both) (i) a strong diapirism since the Upper Jurassic due to the breaking of the initial platform (Nieto *et al.*, 1992), and later emplacement of the Triassic mass to the deformation front or (ii) due to "lateral diapiric emplacement" of Triassic rocks during the orogenic compression (Berástegui *et al.*, 1998). Either way these allocthonous Triassic rocks, loaded with blocks broken off from the Jurassic and Cretaceous overlying sequence, would have been emplaced to the front of the thrust-and-fold belt (Zone II) and has become the main source of the synorogenic foredeep infill (Zone III).

Conclusions

The NW boundary of the Ronda Basin is a WSW-ENE structural high which could be interpreted as a transpressive band controlled by post-Tortonian (i) dextral WSW-ENE strike-slip faults and (ii) SW-NE large-scale folds (iii) together SE-NW normal faults which contribute to along strike stretching and map-scale competent rocks segmentation.

The main dextral strike-slip fault zone is relieved by NW-SE oblique segments, dominated by stretching and shortening structures. We interpret them as releasing and restraining bends respectively.

The structural associations are broadly similar to those of the fold-and-thrust belt proper in the Ronda Basin area, suggesting this zone forms part of the fold-and-thrust proper, therefore localizing the Olistostromic Unit, toward the N of this area.

Acknowledgements

This research is supported by grants RNM-0451 and CGL2013-46368-P. We thank F. Pérez Valera and J.M. Azañon for their comments.

References

Barka, A.A. and Kandinsky-Cade, K. (1988). *Tectonics* 7, 663-684.

Berástegui, X., Banks, C.J., Puig, C., Taberner, C., Waltham, D. and Fernández, M. (1998). *Geological Society Special Publications* 134, 49-68.

Festa, A., Pini, G.A., Dilek, Y. and Codegone, G. (2010). *International Geology Review* 52, 1040-1105.

Jiménez-Bonilla, A., Balanyá, J.C., Expósito, I. and Díaz-Azpiroz, M. (2011). *Geogaceta* 50, 23-26

Jiménez-Bonilla, A., Balanyá, J.C., Expósito, I. and Díaz-Azpiroz, M. (2012). *Geo-Temas* 13, 499-503.

Luján, M., Balanyá, J.C. and Crespo-Blanc, A. (2000). *Comptes-Rendus Académie des Sciences de Paris, Série II*, 330, 631-638.

Nieto, L.M, Molina, J.M. and Ruíz-Ortíz, P.A. (1992). *Revista de la Sociedad Geológica de España* 5, 95-111.

Martín-Algarra, A. (1987). *Evolución geológica alpina del contacto entre las zonas internas y externas de la Cordillera Bética.* Tesis Doctoral, Univ. de Granada, 1171 p.

Pérez-Valera, F. and Pérez-López, A. (2003). *Revista de la Sociedad Geológica de España* 16, 35-50.

Rodríguez-Fernández, J., Roldán, F. J., Azañón, J. M. and García-Cortés, A. (2013). *Boletín Geológico y Minero* 124, 477-504.