Geochronology and detrital zircons sources from the Sierra Albarrana Domain (SW Iberian Massif)

Geocronología y áreas fuente de zircones detríticos del Dominio de Sierra Albarrana (SW Macizo Ibérico)

Byron Solís-Alulima[1], Jacobo Abati[2], Alicia López-Camona[1], Gabriel Gutiérrez-Alonso[3] and Javier Fernández-Suárez[1]

[1] Dpto. de Mineralogía y Petrología, Facultad de Ciencias Geológicas, Universidad Complutense de Madrid 28040, Madrid. bysolis@ucm.es, acarmona@ucm.es, jfsuarez@geo.ucm.es
[2] Dpto. de Mineralogía y Petrología e Instituto de Geociencias (UCM, CSIC), Facultad de Ciencias Geológicas, Universidad Complutense de Madrid 28040, Madrid. abati@ucm.es
[3] Dpto. de Geología, Universidad de Salamanca, 37008, Salamanca. gabi@usal.es

ABSTRACT

This study compiles the U-Pb and $^{40}Ar/^{39}Ar$ geochronology of the metasedimentary, migmatitic and granitic rocks of the Sierra Albarrana Domain, based on data recently published by the authors together with other bibliographic sources. Maximum depositional ages (MDA) and magmatic and metamorphic events ages are discussed.

MDAs suggest that this domain was deposited during the middle Cambrian (ca. 511) and U-Pb ages of zoned magmatic and metamorphic zircon grains indicate that the main tectono-magmatic event is late Cambrian (granite emplacement; 481 ± 2 Ma) to early Ordovician (migmatization; 478 ± 2 Ma). The ^{40}Ar-^{39}Ar ages evidence a Cambro-Ordovician metamorphic event (ca. 482 Ma) and another related to the Variscan Orogeny (ca. 337-392 Ma).

The most important detrital source corresponds to a Cambrian magmatic event (535-515 Ma), probably developed during the initial episodes of the early Paleozoic rifting affecting the N margin of Gondwana. The remaining Mesoproterozoic, Paleoproterozoic and Archean zircon grains would have been contributed by Paleoproterozoic basement and/or older continental crust recycled in the western sections of the Gondwana margin. We suggest that this domain is probably part of the autochthonous section of the Central Iberian Zone (CIZ) and derived from the Saharan Metacraton and/or Tuareg Shield.

Key-words: *U-Pb geochronology, Maximum depositional age (MDA), Cadomian orogen, Cambro-Ordovician magmatism, Sierra Albarrana.*

RESUMEN

Este estudio recopila la geocronología U-Pb y $^{40}Ar/^{39}Ar$ de las rocas metasedimentarias, migmatíticas y graníticas del Dominio de Sierra Albarrana, a partir de datos recientemente publicados por los autores en conjunto con otras fuentes bibliográficas. Se discuten las Edades Máximas de depósito (MDA) y las edades de los eventos magmáticos y metamórficos.

Las MDA sugieren que este dominio se depositó durante el Cámbrico medio (ca. 511) y las edades U-Pb en circones magmáticos y metamórficos zonados indican que el principal evento tectono-magmático es del Cámbrico tardío (emplazamiento del granito; 481 ± 2 Ma) al Ordovícico temprano (migmatización; 478 ± 2 Ma). Las edades ^{40}Ar-^{39}Ar evidencian un evento metamórfico Cambro-Ordovícico (ca. 482 Ma) y otro relacionado con la Orogenia Varisca (ca. 337-392 Ma).

La principal fuente detrítica corresponde a un evento magmático Cámbrico (535-515 Ma), probablemente desarrollado durante los episodios iniciales del rifting paleozoico temprano del margen N de Gondwana. Los restantes circones del Mesoproterozoico, Paleoproterozoico y Arcaico habrían sido aportados por el basamento paleoproterozoico y/o la corteza continental más antigua reciclada al occidente del margen de Gondwana. Sugerimos que este dominio probablemente es parte de la sección autóctona de la Zona Centro Ibérica (ZCI) y procede del Metacratón del Sahara y/o del Escudo Tuareg.

Palabras clave: *Geocronología U-Pb, Edad Máxima de depósito (MDA), Orogenia Cadomiense, Magmatismo Cambro-Ordovícico, Sierra Albarrana.*

Geogaceta, 73 (2023), 71-74
https://doi.org/10.55407/geogaceta95417
ISSN (versión impresa): 0213-683X
ISSN (Internet): 2173-6545

Fecha de recepción: 06/07/2022
Fecha de revisión: 28/10/2022
Fecha de aceptación: 02/12/2022

Introduction

U-Pb dating of zircons is the most versatile geochronological method to unravel the tectono-magmatic evolution of the continental crust. Applied in detrital zircon populations, it is an effective method to assess the provenance of metasedimentary sequences through comparison with possible source areas in older continental blocks. In addition, it can provide useful information for investigating geological affinity and possible correlations between different terrains. Another widely used method is $^{40}Ar/^{39}Ar$, which determines the age of deformation phases recorded by metamorphic rocks.

In SW Iberia, the Sierra Albarrana Domain (SAD) has traditionally been considered a terrain with a Variscan magmatic and metamorphic history related to the Ossa Morena Zone (OMZ, *e.g.*, González del Tánago, 1995). However, recent works suggest a different scenario. Solís-Alulima *et al.* (2020) showed that the main tectonic fabrics, metamorphism, and related magmatism are essentially pre-Variscan (Lower Ordovician), and Díez Fernández and Arenas (2015) propose that SAD would be correlated with the Central Iberian Zone (CIZ).

In this study, we review the U-Pb and $^{40}Ar/^{39}Ar$ ages obtained from SAD and the 'La Cardenchosa' pluton (LCP) with the aim of discussing the origin, geological evolution, and geological affinity of this terrain located in the SW of the Iberian Massif.

Geological Setting

This study focuses on the SAD (Fig. 1A), a metasedimentary sequence that defines an anticlinorium (González del Tánago, 1995), and LCP, a granitic body intruding the metasediments. Stratigraphically, from bottom to top, Insúa *et al.* (1990; Fig. 1B) describe the metasedimentary sequences: (i) Sierra Albarrana (quartzites), (ii) Cabril-Peña Grajera (gneisses, migmatites and amphibolites), (iii) Los Pavillos (schists), (iv) Albariza-Bembézar (And±St±Grt schists), and (v) Azuaga Formation (metapelites).

Previous ages span a wide time range, from Precambrian to Devonian, and correspond to IGME technical reports (*e.g.*, Apalategui *et al.*, 1985), paleontological studies (*e.g.*, Azor *et al.*, 1991), relationships with LCP (López-Guijarro *et al.*, 2008) and comparisons of geochemical features with other areas of the Iberian Massif (Fuenlabrada *et al.*, 2021).

U-Pb Geocronology

Magmatic zircon ages from LCP

The zircon grains of LCP (CZ05; Solís-Alulima *et al.*, 2020) constitute a single population of medium size (60–170 µm) idiomorphic crystals with well-developed oscillatory zoning, characteristic of magmatic zircon from acid igneous rocks. Single U-Pb analytical results provide ages from 469 to 498 Ma with no xenocrystic zircons. The obtained ages can be separated into two coherent groups that provide two different concordia ages. The first group (n = 14) resulted in a concordia age of 481 ± 2 Ma (Fig. 2) while the second one (n = 17) resulted in an age of 494 ± 2 Ma. The first of the reported ages is considered as the intrusion age of LCP, which is coincident with the age obtained by Azor *et al.* (2016). The oldest age opens the possibility of the presence of a complex magmatic crystallization history of LCP or the existence of different magma pulses in the region.

Zircon ages from the migmatites

Zircon crystals of migmatitic leucosomes (AZ06; Solís-Alulima *et al.*, 2020) show clearly defined cores and rims. The cores are mainly oscillatory zoned. Overgrowths are up to 30 µm and have low Th/U ratios (<0.07) in sharp contrast to cores, whose ratio is generally greater than 0.4 (except in older cores). These characteristics indicate that the overgrowths are probably products of metamorphic recrystallization.

10 concordant analyses performed on zircon rims yield a coherent group whose concordia age is 478 ± 2 Ma and can be considered the age of migmatization (Fig 2). Zircon cores define a zircon population dominated by Ediacaran ages (ca. 540-616 Ma) with sparse Cryogenian ages (ca. 680-760 Ma) and Paleoproterozoic grains (ca. 1.9-2.1 Ma).

Detrital zircon ages from SAD

These analyses were compiled from Solís-Alulima *et al.* (2022). The Kernel density estimation plots (KDEs) are drawn in Fig. 2. The Maximum Depositional Ages (MDA) were calculated as the weighted average of the $^{206}Pb/^{238}U$ age of the youngest concordant grains. Comparison of age distributions between samples was made using a Kolmogorov-Smirnov (K-S) test. The multidimensional scaling analysis plots (3D-MDS) were obtained using the data from the SAD and neighbouring areas, with emphasis on the metasedimentary sequences from the Ediacaran to the Cambrian (Cambeses *et al.*, 2017 and references therein).

Concordant analyses of 98 zircons from the Albarrana quartzite (AZ01) yielded concordant ages between 500 ± 70 and 2220 ± 66 Ma, but mostly concentrating between 500 and 1000 Ma. The best estimation of MDA is 511 ± 21 Ma.

A paragneiss from the Cabril-Peña Grajera (AZ03) provided 142 concordant analyses in zircons, which yielded concordant ages between 503 ± 7 and 2422 ± 45 Ma. The MDA can be estimated at 520 ± 8 Ma.

Three samples were collected in Albariza-Bembézar. In the lower part, 118 concordant zircon analyses from a schist (AZ07) yielded concordant ages between 512 ± 31 and 2618 ± 4 Ma, with MDA of 530 ± 9 Ma. Two schists (AZ09, AZ15) of the upper part were sampled on opposite limbs of the Sierra Albarrana anticlinorium. A K-S test indicates that the U-Pb age distribution is not significantly different at the 5% confidence level and, therefore, they can be treated as one single sample (n = 301). Thus, the calculated MDA is 555 ± 2 Ma.

47 concordant zircons of the Azuaga Formation (AZ16) yielded concordant ages between 545 ± 20 and 1928 ± 36 Ma. MDA of 554 ± 8 Ma was obtained.

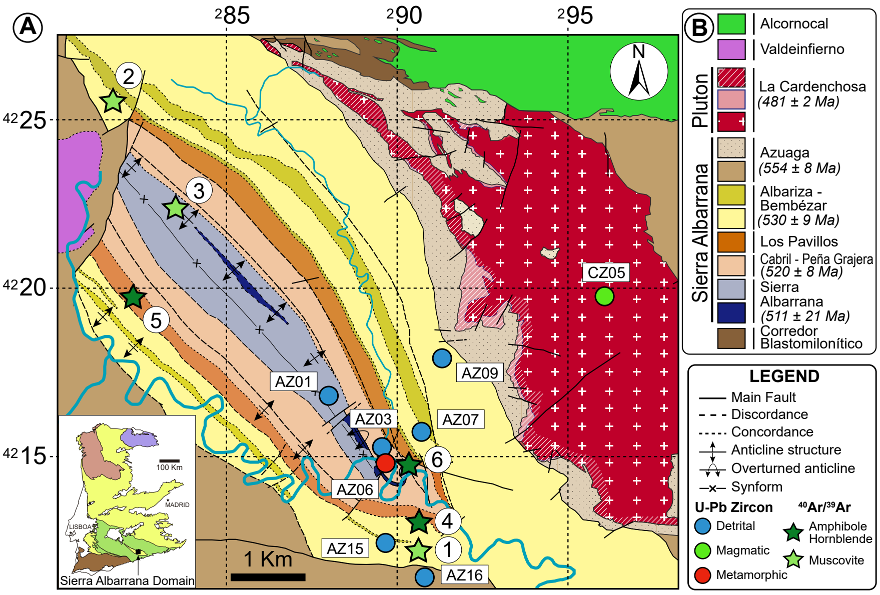

Fig. 1.- A) Geological map of SAD. In the box on the lower left, the location of the domain in the Iberian Massif is indicated; B) Stratigraphic column, simplified from Insúa et al. (1990). The sample locations and MDAs are taken from Solís-Alulima et al. (2020, 2022), Dallmeyer and Quesada (1992) and Azor et al. (2012), reference numbers are shown in Table I.

Fig. 1.- A) Mapa geológico del Dominio de Sierra Albarrana. En el recuadro abajo a la izquierda, se indica la ubicación del dominio en el Macizo Ibérico; B) Columna estratigráfica, simplificado de Insúa et al. (1990). Las ubicaciones de las muestras y las MDAs son tomadas de Solís-Alulima et al. (2020, 2022), Dallmeyer y Quesada (1992) y Azor et al. (2012), los números de referencia se muestran en la Tabla I.

N	Age (Ma)	Mineral	Reference
1	**337 ± 2**	Muscovite	2
2	**351 ± 1**	Muscovite	1
3	**353 ± 1**	Muscovite	1
4	**386 ± 6**	Amphibole	2
5	**392 ± 1**	Hornblende	1
6	**482 ± 4**	Amphibole	2

Table I.- $^{40}Ar/^{39}Ar$ analysis of the Sierra Albarrana Domain. (1) Dallmeyer and Quesada (1992), (2) Azor et al. (2012)

Tabla I.- Análisis $^{40}Ar/^{39}Ar$ del Dominio de Sierra Albarrana. (1) Dallmeyer and Quesada (1992), (2) Azor et al. (2012).

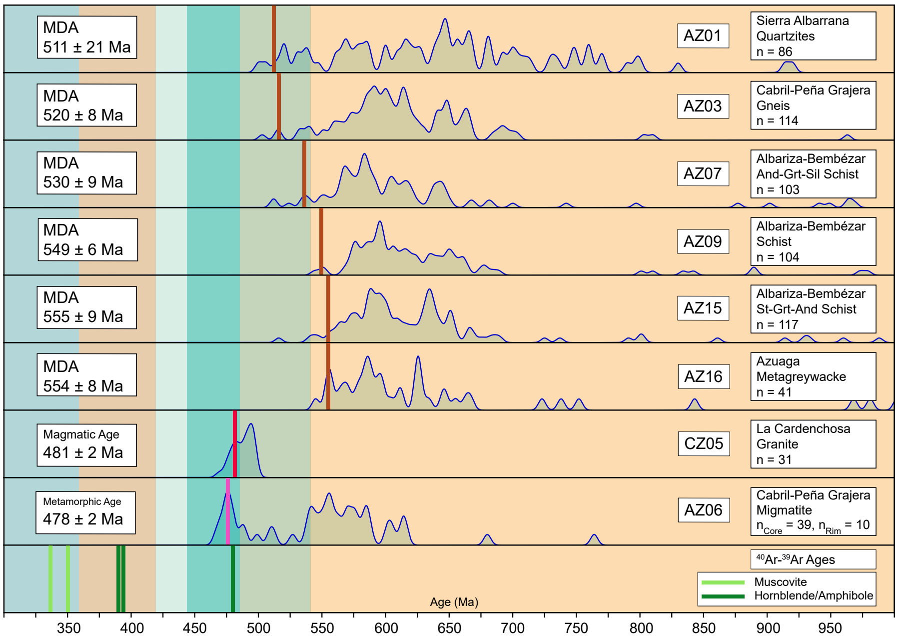

Fig. 2.- KDEs up to 1000 Ma of the SAD. Zircon U-Pb ages were taken from Solís-Alulima et al. (2020, 2022). $^{40}Ar/^{39}Ar$ ages were taken from Dallmeyer and Quesada (1992), and Azor et al. (2012) [details Table I]. MDA (Maximum Depositional Age).

Fig. 2.- KDEs hasta 1000 Ma del Dominio de Sierra Albarrana. Las edades U-Pb en circones son de Solís-Alulima et al. (2020, 2022). Las edades $^{40}Ar/^{39}Ar$ son de Dallmeyer and Quesada (1992), y Azor et al. (2012) [detalles en la Tabla I]. MDA (Edad Máxima de depósito).

$^{40}Ar/^{39}Ar$ Ages

We have compiled the ages obtained by this method (Table I) and plotted them together with the U-Pb ages for comparison (Fig. 2).

Discussion

Magmatic and metamorphic ages

The metamorphic and magmatic evolution of the SAD has generally been attributed to the Variscan cycle (*e.g.*, Dallmeyer and Quesada, 1992). Recently, Azor *et al.* (2012) proposed an older low-pressure metamorphic event related to continental rifting leading to the onset of the Variscan cycle. Based on these results it has been proposed that the main regional fabric in the SAD could be Cambro-Ordovician and be related to Cadomian magmatism (Solís-Alulima et al., 2022). Furthermore, the LCP, which is part of the Cambro-Ordovician igneous suite (ca. 478-480 Ma; Azor *et al.*, 2016), crosses a pervasive synmetamorphic cleavage, supporting a Cambro-Ordovician age for SAD metamorphism.

Geochronology data presented by Solís-Alulima *et al.* (2020) confirm the Early Ordovician age (481 ± 2 Ma) previously attributed to LCP and ductile deformation developed under high-grade metamorphic conditions in the SAD. Field cross-cutting relationships suggest that the regional metamorphic fabrics of the SAD are older than the granite emplacement. In addition, the metamorphic ages obtained at the zircon rims of the migmatitic gneisses of the lower SAD successions are identical, within errors, to the age attributed to the LCP emplacement (~481 Ma), suggesting a common origin for the tectonic-metamorphic migmatitic banding in the basal parts of the SAD and the LCP emplacement.

The $^{40}Ar/^{39}Ar$ ages (Dallmeyer and Quesada, 1992; Azor *et al.*, 2012) represent a very wide age range. The oldest age (ca. 482 Ma), obtained from an amphibolite collected from the Cabril-Peña Grajera succession, could be related to a Cambro-Ordovician metamorphic event, while the youngest (ca. 337 – 392 Ma) would be related to the Variscan Orogeny and would correspond to reset ages.

Depositional age and stratigraphy

The Albarrana Succession forms the lower part of the SAD. If we consider its MDA, the age of the LCP (481 ± 2 Ma) intruding the Azuaga Formation, as well as a metamorphic age (478 ± 2 Ma) for the migmatites overlying this succession (Cabril-Peña Grajera) we can conclude that the basin-filling of the SAD began in the middle Cambrian to early Ordovician (Solís-Alulima *et al.*, 2022).

KDEs from SAD (Fig. 2) show a dominant age group in the Ediacaran-Cryogenian (c. 0.54–0.72 Ga), and two minor age groups in the Tonian (c. 0.72–1.0 Ga) and Paleoproterozoic (c. 1.6–2.5 Ga). This suggests that the principal detrital source corresponds to Cadomian magmatism (535-515 Ma). Mesoproterozoic, Paleoproterozoic, and Archean zircons would have been contributed by Paleoproterozoic basement and/or recycled continental crust in the eastern sections of the Gondwana margin.

Sample comparison: multidimensional scaling

Results from the samples of SAD were integrated for comparison by Solís-Alulima *et al.* (2022). The 3D-MDS plot (Fig. 3) suggests that the Albarrana Succession (AZ01) is regionally akin to the Lower Unit of the Schist Greywacke Complex (SGC – CIZ). The Cabril-Peña Grajera (AZ03) and the upper part of the Albariza-Bembézar (AZ09-15) show strong resemblances with the Upper Alcudian Formation (CIZ). The lower part of the Albariza-Bembézar (AZ07) has a closer affinity with the Beiras Group (CIZ). Finally, the Azuaga Formation (AZ16) is nearer to the Cándana Formation in the West-Asturian-Leonese Zone (WALZ).

López-Guijarro *et al.*, (2008) proposed that the SAD and the Serie Negra had a common detrital source and linked it to the OMZ. However, considering the possible difficulties in differentiating the OMZ from the Iberian autochthonous based on the age populations of detrital zircons, the comparison diagrams (Cumulative age distribution – CADs, 3D-MDS; Solís-Alulima *et al.*, 2022), together with the Cambrian zircons obtained from SAD, indicate that these domains do not share a common source (Solís-Alulima *et al.*, 2022). In addition, SAD geochemical and isotopic characteristics are very similar to those found in the sedimentary sequences of the autochthonous section of the CIZ (Fuenlabrada *et al.*, 2021). These considerations strongly suggest that SAD could correlate with the autochthonous domains of the CIZ. Furthermore, based on comparison diagrams (3D-MDS), the Azuaga Formation shows a higher affinity with WALZ, also part of the Iberian autochthonous.

Possible settings and sources

According to Fuenlabrada *et al.* (2021), the SAD has very similar lithogeochemical and Sm-Nd isotopic signatures suggesting

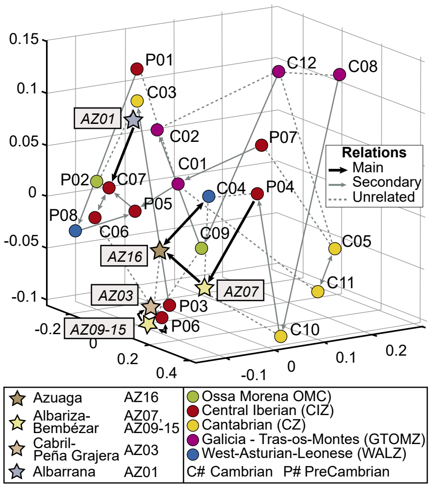

Fig. 3.- Multidimensional scaling plot (3D-MDS) of Precambrian-Cambrian samples from the Iberian Massif and SAD's samples. Modified from Solís-Alulima et al. (2022).

Fig. 3.- Gráfico de escalamiento multidimensional (3D-MDS) de muestras precámbricas-cámbricas del Macizo Ibérico y muestras del DSA. Modificado de Solís-Alulima et al. (2022).

derivation from the same source. U-Pb detrital zircons ages presented by Solís-Alulima *et al.* (2022) are in good agreement with this interpretation. A generalized convergence during the Neoproterozoic generated an important relief and detritus coming from these arc and fore-arc sections fed the Ediacaran-Cambrian back-arc basin. Díez Fernández and Arenas (2015) reinterpret the meaning of the SAD as an autochthonous terrane that could be the continuation of the autochthonous CIZ below the OMZ.

The zircon age pattern of the SAD, characterized by a high percentage of Neoproterozoic zircon with Ediacaran (541–635 Ma) and Cryogenian (635–720 Ma) populations, and additional Mesoproterozoic, Paleoproterozoic, and Archean zircons, is typical of sediments derived from the northern margin of Gondwana. The main source of Neoproterozoic zircon grains would correspond to Cadomian igneous rocks developed in the magmatic arc, whose associated back-arc extension would be related with the beginning of the installation of a long-lived passive margin in northern Gondwana at the Ediacaran-Cambrian boundary (c. 540 Ma). The Ediacaran peak and the presence of a minor percentage of Mesoproterozoic ages suggest the Saharan Metacraton was the main provenance. However, the Paleoproterozoic peak (2000 Ma) would also point to the Tuareg Shield as the other possible source through the Saharan platform (Cambeses *et al.*, 2017; Fuenlabrada *et al.*, 2021).

Conclusions

1. U-Pb ages of magmatic and metamorphic zircon grains indicate that the main tectono-magmatic event in the SAD is Lower Ordovician (granite emplacement; 481 ± 2 Ma and migmatization; 478 ± 2 Ma). This setting and timing are compatible with the late magmatic event defined for the Early Paleozoic rifting (535–460 Ma).

2. The oldest $^{40}Ar/^{39}Ar$ age (ca. 482 Ma) could be related to a Cambro-Ordovician low-pressure metamorphic event, while the young ages (ca. 337-392 Ma) would be related to the Variscan Orogeny.

3. The SAD was deposited in the middle Cambrian. This age is bounded by the MDA of the Albarrana succession (511 ± 21 Ma) and the magmatic age of LCP (481 ± 2 Ma), and the metamorphic age in the migmatites of the Cabril-Peña Grajera Succession (478 ± 2 Ma).

4. The MDAs in SAD, from bottom to top, are: Albarrana (511 ± 21 Ma), Cabril-Peña Grajera (520 ± 8 Ma), Albariza- Bembézar (530 ± 9 Ma - bottom; 555 ± 2 Ma - top) successions and the Azuaga Formation (554 ± 8 Ma).

5. The principal detrital source corresponds to Cadomian magmatism developed in the early magmatic event (535–515 Ma). Mesoproterozoic, Paleoproterozoic, and Archean zircons would have been contributed by Paleoproterozoic basement and/or ancient continental crust recycled in the eastern Gondwana margin.

6. U-Pb zircon data, geochemical and isotopic characteristics, and regional comparisons strongly suggest that SAD is part of the autochthonous section of the CIZ. Zircon age patterns suggest a sedimentary provenance from the Sahara Metacraton and/or the Tuareg Shield.

Authors' contribution

Solís-Alulima, B.; Paper Structure, methodology, data acquisition, editing, figures, research/analysis.

Abati, J.: Methodology, manuscript review, coordination, supervision.

López-Carmona, A.: Methodology, manuscript review, coordination, supervision.

Gutiérrez-Alonso, G.; Methodology, manuscript review.

Fernández-Suárez, J.; Methodology, manuscript review.

Acknowledgements

This work was supported by projects CGL2016-76438-P, PID2020-112489GB-C21, and PID2021-126347NB-I00. Solís-Alulima is funded by the predoctoral contract CT17/17-CT18/17 (UCM-Santander) We appreciate the constructive reviews from anonymous reviewers that have significantly improved the quality of the manuscript.

References

Apalategui, O., Borrero, J., Higueras, P. y Roldán, F. (1985). *Mapa Geológico de España 1:50.000, hoja nº 878 (Azuaga) y memoria*. IGME, Madrid, 48 p.

Azor, A., González Lodeiro, F., Marcos, A., Simancas, J. (1991). *Geogaceta* 10, 119-124.

Azor, A., Simancas, J., Martínez Poyatos, D., Montero, P., Bea, F., González Lodeiro, F. y Gabites, J. (2012). En: VIII Congreso Geológico de España. *Geo-Temas* 13, 341-344.

Azor, A., Simancas, J., Martínez Potayos, D., Montero, P., González Lodeiro, F. y Pérez-Cáceres, I. (2016). En: IX Congreso Geológico de España. *Geo-Temas*, 16: 23-26.

Cambeses, A., Scarrow, J., Montero, P., Lázaro and C., Bea, F. (2017). *Int. Geol. Rev.* 59 (1), 94-130. https://doi.org/jbsn

Dallmeyer, R. and Quesada, C. (1992). *Tectonophysics* 216 (3-4), 339-364. https://doi.org/ddhtmp

Díez Fernández, R. and Arenas, R. (2015). *Tectonophysics* 654, 96-100. https://doi.org/f7knjn

Fuenlabrada, J., Arenas, R., Díez Fernández, R., González del Tánago, J., Martín-Parra, L., Matas, J., Rojo-Pérez, E., Sánchez Martínez, S., Andonaegui, P. and Solís-Alulima, B. (2021). *Journal of Iberian Geology* 47, 121-150. https://doi.org/jbsp

González del Tánago, J. (1995). *El núcleo metamórfico de Sierra Albarrana y su campo de pegmatitas graníticas asociado. Macizo Ibérico, Córdoba, España*. Tesis Doctoral, Univ. Complutense, 472 p.

Insúa, M., Carvajal, A. y Huerta, J. (1990). *Mapa Geológico de España 1:50.000, hoja nº 900 (La Cardenchosa) y memoria*. IGME, Madrid, 80 p.

López-Guijarro, R., Armendáriz, M., Quesada, C., Fernández-Suárez, J., Murphy, J., Pin, C. and Bellido, F. (2008). *Tectonophysics* 461, 201-214. https://doi.org/ckmkjj

Solís-Alulima, B., López-Carmona, A. and Abati, J. (2020). *Lithos* 374-375, 105700. https://doi.org/jbss

Solís-Alulima, B., Abati, J., López-Carmona, A., Gutiérrez-Alonso, G., Fernández-Suárez J. and Stockli, D. (2022). *Lithos* 408-409, 106542. https://doi.org/jbsr