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Hf isotopes in detrital zircon grains of the Sierra Albarrana Domain (SW Iberian Massif): Eburnean vs. Archaean basement signatures

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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. Stockli, D.: Methodology, data acquisition.

ABSTRACT

This study presents Lu–Hf data on detrital zircon grains from the Lower Paleozoic metasedimentary successions of the Sierra Albarrana Domain (SW Iberian Massif). We provide new information about their origin, record of continental crustal evolution, and geological affinity. Previous detrital zircon U–Pb data in this terrane reveal two main age populations, with age peaks at c. 595 Ma and c. 1.90 Ga. The Ediacaran events are interpreted to represent a magmatic arc with input of juvenile magmas intruding into the Eburnean basement of Gondwana, and probably mixing with it. The different evolutionary stages of the arc were probably linked to the Cadomian Orogeny during Neoproterozoic-earliest Cambrian times. The Paleoproterozoic zircon population corresponds to the Eburnean orogeny. The magmas derived from an Eburnean depleted mantle partly intruded an older basement, leading to an incipient mixing process. ϵ_{Hf} isotopic compositions indicate a possible affinity with the Central Iberian Zone suggesting a common geological setting during Ediacaran-Cambrian times, but different during the Paleoproterozoic.

Keywords

Hf isotopes, U-Pb age, detrital zircon, Central Iberian Zone, Sierra Albarrana

U–Pb geochronology and Lu–Hf isotopes of detrital zircon populations are effective methods to place constraints on the provenance of metasedimentary sequences by comparison with possible source areas in older continental blocks (e.g., Fernández-Suárez et al., 1999; Orejana et al., 2015). Hf isotope data can provide a more precise identification of mantle source domains, as well as a record of the continental crustal evolution (e.g., Teixeira et al., 2011). In this study, we present Lu–Hf (MC-ICP-MS) analyses of detrital zircon grains from the metasiliciclastic rocks of the Sierra Albarrana

Domain (SAD), a key domain within the west European Variscan Belt. Additionally, Lu–Hf results are compared with the whole-rock Sm–Nd data obtained by López-Guijarro et al. (2008) and Fuenlabrada et al. (2021) for the same and adjacent domains. All these data are used to investigate the origin, the continental crustal evolution, and the geological affinity of this terrane located in the SW Iberian Massif.

The Iberian segment of the European Variscan belt shows an excellent and almost continuous cross-section of the Variscan orogen. In the last decades, several studies have attempted to locate the relative position of the different Iberian Variscan terranes along the northern paleomargin of Gondwana (Linnemann et al., 2008; Sánchez-García et al., 2008, 2014; Díez Fernández et al., 2010; Pereira et al., 2012a, 2012b; Zimmermann et al., 2015; Henderson et al., 2016; Cambeses et al., 2017 and references therein). Some of these terranes are characterized by a complex poly-orogenic history beginning in the Cadomian cycle (Ediacaran to Cambrian times) and culminated during the Variscan cycle with the final collision between Gondwana and Laurussia (e.g., Díez Fernández et al., 2010; Pereira et al., 2012a, 2020). The record of the pre-Variscan geodynamic evolution begins with the development of an Andean-type active margin (c. 640–545 Ma), most likely related to the Neoproterozoic-Cambrian system of subduction related magmatic arcs and back-arc basins that flanked North Gondwana at that time (Murphy et al., 2004; Linnemann et al., 2008; Pereira et al., 2012a, 2012b).

Subsequently, a major shift in the tectonic regime resulted in the onset of ensialic rifting (c. 535–460 Ma) that led to the Rheic Ocean opening (Chichorro et al., 2008, 2017; Linnemann et al., 2008). The tectonic switch to an anorogenic setting was characterized by voluminous bimodal rift magmatism during the Cambrian and Early Ordovician (Sánchez-García et al., 2003, 2014; Pereira and Quesada, 2006; Chichorro et al., 2008).

After a passive margin episode, the final closure of the Rheic ocean gave way to the

Variscan collision in Late Devonian-Lower Carboniferous times (e.g., Simancas et al., 2001; Pereira et al., 2017; Álvaro et al., 2020).

The SAD, one of these terranes and the object of this study, is located in the southern branch of the Variscan Orogen in SW Iberia, where different geotectonic zones are distinguished building up the Variscan orogenic edifice (Fig. 1a; Julivert et al., 1972). Traditionally, the SAD has been included in the Ossa-Morena Complex (OMC, e.g., Insúa et al., 1990 and references therein), and its magmatic and metamorphic history has been attributed to the Variscan cycle (e.g., González del Tánago 1995; Dallmeyer and Quesada, 1992, Azor et al., 2004). However, recent geochemical and isotopic studies (Fuenlabrada et al., 2021) and detrital zircon U–Pb data (Solís-Alulima et al., 2022) suggest that this domain (i) may be part of the so called autochthonous Central Iberian Zone (CIZ); (ii) its most important local detrital source corresponds to Cadomian magmatism, (iii) its sedimentary provenance may have been located in the present-day Saharan Metacraton and/or the Tuareg Shield, and (iv) the highest grade tectono-metamorphic event recorded in the rocks may not be Variscan, but may correspond to the cambro-ordovician extensional event (Solís-Alulima et al., 2020) widely recognized in western Europe related to the opening of the Rheic ocean.

The SAD is a mountainous alignment that defines a NW–SE oriented anticlinorium corresponding to an elongated thermal dome (e.g., Azor et al., 1992; González del Tánago, 1995). Insúa et al. (1990) proposed a stratigraphic sequence consisting of the following successions from bottom to top: Albarrana (quartzites and amphibolites); Cabril-Peña Grajera (gneisses and migmatites); Cerro de Los Pavillos (biotite gneiss and mica-schists); Albariza-Bembézar (andalusite and/or staurolite and/or garnet mica-schists, muscovite-bearing schists and orthogneisses) and the Azuaga Formation (laminated metapelites, metaquartzites, and metagreywackes) (Fig. 1b, c). The whole

succession was deposited during the middle Cambrian (Solís-Alulima et al., 2022) and records low-pressure ordovician (c. 478 Ma) metamorphism (Azor and Ballèvre, 1997; Solís-Alulima et al., 2020; Solís-Alulima et al., under review).

METHODOLOGY

Hafnium isotope measurements on zircon were performed at the Jackson School of Geosciences at the University of Texas at Austin using a Nu Plasma 3D MC-ICP-MS (NuP3D) and an ESL NWR 193 nm laser ablation system. The NP3D was tuned for Hf using solution standards and then hot switched to the laser sample introduction system. Laser and plasma gasses were tuned for maximum Hf signal intensity and quadrupole lenses adjusted for best peak shape using ablated line scans across zircon standards.

Measurements were made using time-resolved analysis. Upon completion of a sequence, integration windows were hand-picked based on Hf signal intensities. On-peak zeros were measured for 1 minute prior to each measurement by analyzing signal intensities of each mass with all gases flowing but without the laser pulsing. For each analysis data were collected for 1 minute. Some zircons were too thin and the laser penetrated through the zircon in less than 1 minute. These analyses are noted and have higher uncertainties. ^{176}Hf is corrected for interferences of ^{176}Yb and ^{176}Lu by measuring ^{173}Yb , ^{171}Yb and ^{175}Lu . The mass bias correction of both Yb and Lu was made using an exponential fractionation law and $^{173}\text{Yb}/^{171}\text{Yb} = 1.132685$. Mass bias-corrected values ^{176}Lu and ^{176}Yb were determined by measuring ^{175}Lu and ^{173}Yb and accepted ratios of $^{176}\text{Lu}/^{175}\text{Lu} = 0.02655$ and $^{176}\text{Yb}/^{173}\text{Yb} = 0.796218$. After interference corrections, all Hf ratios are corrected for analytical mass bias using an exponential fractionation equation and the value $^{179}\text{Hf}/^{177}\text{Hf} = 0.7325$. During the analytical session, zircon standard Plesovice was used as a bracketing standard and analyzed at least every 7 unknowns. Secondary zircon standard FC1 was treated as an unknown to establish

accuracy and reproducibility of the analytical procedure. FC1 has relatively high REE concentrations and demonstrates effectiveness of Yb and Lu corrections on ^{176}Hf . For each analysis, precision of sample ratios reflects 2 standard error internal precision. Reproducibility of FC1, reported as two-standard deviations (2SD) should be used to indicate precision of sample measurements, except where internal precision of individual analyses is large.

Epsilon Hf values were calculated using the CHUR values from Bouvier et al., 2008 ($^{176}\text{Hf}/^{177}\text{Hf} = 0.282785$ and $^{176}\text{Lu}/^{177}\text{Hf} = 0.033600$). Back calculation of ratios to the time of zircon crystallization uses the ^{176}Lu decay constant $1.867 * 10^{-5}$ (Soderlund et al., 2004) and measured Lu and Hf ratios of the zircons. For depleted mantle model ages, a two-stage model is used to back calculate sample ratios to the intersection with the depleted mantle curve. Sample $^{176}\text{Lu}/^{177}\text{Hf}$ are used to back calculate sample $^{176}\text{Hf}/^{177}\text{Hf}$ to the time of zircon crystallization. From the time of crystallization to the time of intersection with the depleted mantle model curve the bulk earth $^{176}\text{Lu}/^{177}\text{Hf}$ ratio of 0.015 (Goodge and Vervoort, 2006) is used to age correct sample $^{176}\text{Hf}/^{177}\text{Hf}$ ratios. For the depleted mantle, the Lu and Hf ratios of Vervoort and Blichert-Toft (1999) were used, $^{176}\text{Hf}/^{177}\text{Hf} = 0.282225$ and $^{176}\text{Lu}/^{177}\text{Hf} = 0.038512$.

SAMPLE DESCRIPTION

We selected three samples from the SAD (Fig. 1b). A quartz-feldspathic biotite gneiss (AZ03) from the Cabril-Peña Grajera Succession, that shows fine-grained granolepidoblastic texture with quartz, K-feldspar, and biotite. Minor and accessory minerals are sillimanite, ilmenite, and zircon. A micaschist (AZ09) and a staurolite-andalusite schist (AZ15) from the Albariza-Bembézar Succession were also sampled. The micaschist presents a fine-grained matrix with garnet-porphyroblasts, quartz,

muscovite, and plagioclase. Minor minerals are graphite, sericite, chlorite, ilmenite, and zircon. The staurolite-andalusite schist contains staurolite, andalusite, and garnet porphyroblasts on a medium-grained matrix with quartz, muscovite, sillimanite, biotite, and plagioclase. Minor and accessory minerals are graphite, ilmenite, and zircon.

RESULTS

From the 443 spots for U-Pb analyses on zircon cores (and yielding concordant ages; Solís-Alulima et al., 2022), 144 were selected for Lu-Hf isotope analyses (Appendix 1). Around 22 % of analyses provided positive $\epsilon_{\text{Hf}(t)}$. Neoproterozoic zircon grains in the ϵ_{Hf} vs. age diagram (Fig. 2) show a rather continuous range of epsilon values, from strongly negative to values close to the DM evolution line. The group of positive $\epsilon_{\text{Hf}(t)}$ zircons ($n = 16$; from +0.3 to +8.7 epsilon units) points to the production of some juvenile (depleted mantle-derived) magmas between c. 540 and 660 Ma, most of them crystallizing at c. 595 Ma. Zircons with negative $\epsilon_{\text{Hf}(t)}$ ($n = 95$) show a wide range of values, down to -24.3ϵ units. This pattern of epsilon values is compatible with a mixing process between juvenile magmas and an older crustal component with strongly negative ϵ_{Hf} values. This scenario would require the juvenile magmas to have mixed with a source whose $\epsilon_{\text{Hf}(t)}$ values at c. 595 Ma were ≤ -10 to acquire the observed range of strongly negative values (-10 to $-24.3 \epsilon_{\text{Hf}(t)}$) in the studied zircon grains. Following the evolutionary array in Fig. 2, the older crustal component could be represented by the c. 2.0 Ga zircons that lie on the Eburnean crust evolution trend. Some of the $\epsilon_{\text{Hf}(t)}$ zircon grains between c. 540–640 Ma plot around, or slightly above, the CHUR evolution trend, while most of them depict negative values. This Hf isotopic signature has been interpreted to be the result of a fairly continuous mixing of juvenile material and varied continental basement sources in a magmatic arc setting in the periphery of

Gondwana (e.g., Albert et al., 2015; Andonaegui et al., 2016). These observations agree with the record of the geodynamic evolution of the active margin during the Cadomian Orogeny (c. 640–545 Ma) (Dallmeyer and Quesada, 1992; Pereira and Quesada, 2006; Linnemann et al., 2008). The apparent intensity of recycling of an older crust point to the internal part of an ensialic magmatic arc.

Paleoproterozoic zircon grains show Hf isotopic features similar to those of their Cadomian counterparts. There are zircon crystals with positive $\epsilon\text{Hf}(t)$ values ($n = 11$; from +0.1 to +4.7 epsilon units) and TDM values from c. 2.4 to 3.0 Ga, which we interpret to correspond to a magmatic event, with crystallization ages concentrated between ca. 2.1 and 1.9 Ga. This interval falls within the timespan assigned to the Eburnean Orogeny (c. 1.8–2.2 Ga; Ennih and Liégeois, 2008). Zircons with negative ϵHf values ($n = 22$; from –0.9 to –22.6 epsilon units) may also represent a mixing process between ca. 2 Ga DM-derived magmas and older rocks, probably from an Archean basement.

The apparent Paleoproterozoic evolution is comparable to that of the rocks sourced in West African Craton (e.g., Abati et al., 2010). However, the Paleoproterozoic peaks (~1.9 and ~ 2.1 Ga) could also point to the Tuareg Shield as another possible source through the Saharan platform (Cambeses et al., 2017; Fuenlabrada et al., 2021; Lains et al., 2022).

DISCUSSION

In the stratigraphic sequence of the Sierra Albarrana Domain (SAD), previous isotopic work was limited to two studies on whole-rock Sm–Nd isotope systematics. López-Guijarro et al. (2008) considered an Ediacaran age for the basal part of the sequence (c. 570 Ma) and suggested that its source was an older Archean/Paleoproterozoic

continental crust linked to a passive margin depositional environment located in the westernmost sections of the Gondwanan margin. Fuenlabrada et al. (2021) proposed a younger Early Cambrian age (c. 530 Ma) and suggest no significant variations in the different successions, a probable common source, and that the sediments are compatible with older reworked materials with continental crust affinity and limited contributions from juvenile sources. The Nd model ages obtained in both works cited above are similar (TDM ~ 1400 – 1900 Ma, Fig. 3a). Comparison of the Sm–Nd isotopic characteristics of the SAD, other OMC terranes, and the CIZ metasedimentary units show no significant differences, suggesting that they shared the same sources, at least since the latest Ediacaran throughout the Paleozoic (López-Guijarro et al., 2008). The $\epsilon_{\text{Hf}}(t)$ obtained in this work and associated with the Cadomian magmatic arc (c. 640–545 Ma) confirm that the SAD materials are mostly derived from an ancient continental crust (Eburnean-Archaean basement) and have limited contributions from juvenile sources (Cadomian basement). On the other hand, the values obtained for the different samples are very similar to each other (Fig. 2), reinforcing the proposition that there are no significant variations between the sedimentary sources of the different successions.

According to Solís-Alulima et al. (2022), the maximum depositional age (MDA) of the SAD is c. 511 Ma. This age corresponds to the Sierra Albarrana quartzite in the lower part of the stratigraphic sequence. For the samples studied in this work, the specific MDAs are c. 520 Ma (Cabril-Peña Grajera; AZ03) and c. 549 Ma (AZ09) and 555 Ma (AZ15) (Albariza-Bembézar). Both successions lie in the lower and middle section of the stratigraphic sequence respectively (Fig. 1b). The reversed order of their MDAs is consistent with a back-arc basin with a common sediment source in which progressively older rocks are unroofed and eroded (e.g., Malkowski et al., 2018). The KDE plot of Fig. 2 reveals two main age populations, with age peaks at c. 595 Ma (Ediacaran-

Cryogenian population: ~69%), c. 1.90 Ga and 2.1 Ga (Paleoproterozoic population: ~21%). Tonian populations comprise around 5%. Cambrian and Archean populations are 2% and Mesoproterozoic zircons are very scarce with only 1%. This zircon age pattern is typical of sediments derived from the northern margin of Gondwana (e.g., Talavera et al., 2012; Solís-Alulima et al., 2022).

The Paleoproterozoic zircon population falls within the time span of the Eburnean orogeny (2.2–2.0 Ga according to Egal et al., 2002, or 1.8–2.2 Ga according to Ennih and Liégeois, 2008), so the Paleoproterozoic zircon grains of the SAD are possibly derived from rocks generated or reworked during this orogeny. Eburnean age zircon crystals (c. 2.19–1.86 Ga) are arranged as a cluster with a few positive $\epsilon\text{Hf}(t)$ values, which may represent a mixture of juvenile magmas with an older (Archean?) crustal component, and a majority of analyses with negative $\epsilon\text{Hf}(t)$ values suggesting either a more extensive mixing process of juvenile and older crustal components or admixtures of crustal components whose positive end member was not necessarily a ca. 2 Ga juvenile input. As the most negative $\epsilon\text{Hf}(t)$ value for a single Paleoproterozoic zircon grain is -22.6 and the rest of the Paleoproterozoic array intersects at c. 1.8 Ga and c. $\epsilon\text{Hf}(t) = -7$ (Fig. 2), the older crustal component could well have been an Archean crust represented by the sparse SAD Archean zircon grains. These observations are consistent with the geodynamic setting proposed by Egal et al. (2002), where the Eburnean was an active margin orogen formed by oceanic subduction along the edge of a pre-existent Archean craton.

The most important age cluster in the SAD ranges between c. 700–540 Ma, which coincides with the reported ages for the Cadomian Orogeny (c. 750–540 Ma, e.g., Linnemann et al., 2014). The Lu–Hf isotopic pattern (Fig. 2) shows that the c. 700–540 SAD zircons are arranged as a small group with positive $\epsilon\text{Hf}(t)$ values plotting near the

DM evolution trend and as a significant negative $\epsilon_{\text{Hf}}(t)$ arrangement. These patterns can be explained (but do not prove) by the intrusion of juvenile magmas that mainly interacted with Eburnean crust, although the participation of an Archean crustal component cannot be ruled out. Neoproterozoic zircon grains show variable $\epsilon_{\text{Hf}}(t)$, with a predominance of negative values, indicative of possible older crustal recycling with involvement of juvenile components during the Cadomian Orogeny. These results are in agreement with the conclusions obtained in previous studies (López-Guijarro et al., 2008; Fuenlabrada et al., 2021) based on whole rock Sm–Nd isotopic signatures.

Traditionally, the SAD has been associated with the Ossa-Morena Complex and compared with the Serie Negra (López-Guijarro et al., 2008). Recent studies (e.g., Díez Fernández and Arenas, 2015; Abati et al., 2018; Fuenlabrada et al., 2021; Solís-Alulima et al., 2022) have proposed that instead, it would be part of the autochthonous section of the CIZ. Results from the samples of the SAD were integrated for comparison into an $\epsilon_{\text{Hf}}(t)$ dataset with the published data for the metasedimentary rocks of the Iberian Massif (Table 1, Appendix 2; Fig. 3b, c d). There are no published Hf data on equivalent rocks in age of the OMC for comparison, and further research is needed in order to place tighter constraints on whether this terrane was part of the CIZ or of the OMC.

The graph of Fig. 3 shows the apparent affinity of the SAD with the CIZ (Fig. 3b). The main similarity is found in the Neoproterozoic zircon grains, mainly from the Schist Greywacke Complex (Orejana et al., 2015), which show variable $\epsilon_{\text{Hf}}(t)$ and a similar range of values between -25 and +10, indicative of the involvement of juvenile components, associated with the Cadomian Orogeny and a mixing process, and of the recycling of older crust, associated with the Eburnean Orogeny.

The Hf isotopic compositions of the Paleoproterozoic zircon grains from SAD show a narrower range of $\epsilon\text{Hf}(t)$ values than those of the samples from the CIZ and CZ-WALZ used for comparison (Fig. 3b, c, d) which also show a larger population of Archean zircon grains. Despite these minor differences, these observations suggest a possible affinity between the SAD with the CIZ and a common geological setting during the Ediacaran, but possibly different settings during the Paleoproterozoic.

CONCLUSIONS

The Ediacaran events recorded in the SAD detrital zircon populations likely represent (the dismantling of) a magmatic arc at the periphery of the North Gondwana margin. This arc records the intrusion of c. 595 Ma (likely partly juvenile) magmas mainly into the Eburnean basement of northern Gondwana. The different stages of the arc were probably linked to the Cadomian Orogeny in Neoproterozoic-Cambrian times (c. 640–545 Ma), during the development and demise of an Andean-type active margin.

The Paleoproterozoic zircon population falls within the time span of the Eburnean orogeny (1.8–2.2 Ga). Then, the Paleoproterozoic materials of the SAD are possibly derived directly from rocks generated during this orogeny or reworked into the Cadomian subduction related orogenic complex.

ϵHf isotopic compositions suggest an affinity between the SAD and the CIZ and are compatible with a common geological setting during Ediacaran-Cambrian times, but different during the Paleoproterozoic. Nevertheless, the lack of comparable data from the OMC does not allow to rule out an affinity with it.

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FIGURE CAPTIONS

Figure 1. a) Schematic geological map of the Iberian Massif showing the location of the study area (modified from Díez Fernández and Arenas, 2015); b) Geological map, and c) stratigraphic column from the SAD (simplified from Insúa et al.,1990). CZ – Cantabrian Zone, WALZ – West Asturian-Leonese Zone, CIZ – Central Iberian Zone, GTMZ – Galicia-Trás-os-Montes Zone, OMC – Ossa-Morena Complex, SPZ – South-Portuguese Zone

Figure 2. Hf isotope evolution diagram showing SAD zircon data. Kernel Density Estimation of analysed zircon grains with Lu–Hf systematics is represented in grey. KDE and percentage of zircon populations bar (top right) taken from Solís-Alulima et al. (2022). CHUR – Chondritic uniform reservoir; DM – depleted mantle

Figure 3. a) Nd-TDM model ages from the SAD and metasedimentary units of the CIZ and OMC. Modified from Fuenlabrada et al., (2021) and López-Guijarro et al. (2008). ϵ_{Hf} vs. U–Pb ages of detrital zircon grains from metasedimentary units of b) Central Iberian Zone, c) Cantabrian and West Asturian-Leonese Zones, and d) Galicia-Trás-os-Montes Zone. The fields of data from this study are represented by vertical rectangles with red rims. $\epsilon_{\text{Hf}}(t)$ values labelled as Fernández-Suárez et al. (2014), Gutiérrez-Alonso et al. (2015), Pastor-Galán et al. (2013) and Shaw et al. (2014) correspond to values measured by Henderson et al (2016) on zircon ages of known ages reported in the mentioned references.

TABLE

Table 1. ϵ_{Hf} data references used for comparison and correlation.

APPENDIX

Appendix 1. Lu–Hf isotope data of detrital zircon grains from SAD.

Appendix 2. ϵ_{Hf} data from the Iberian Massif for regional comparison

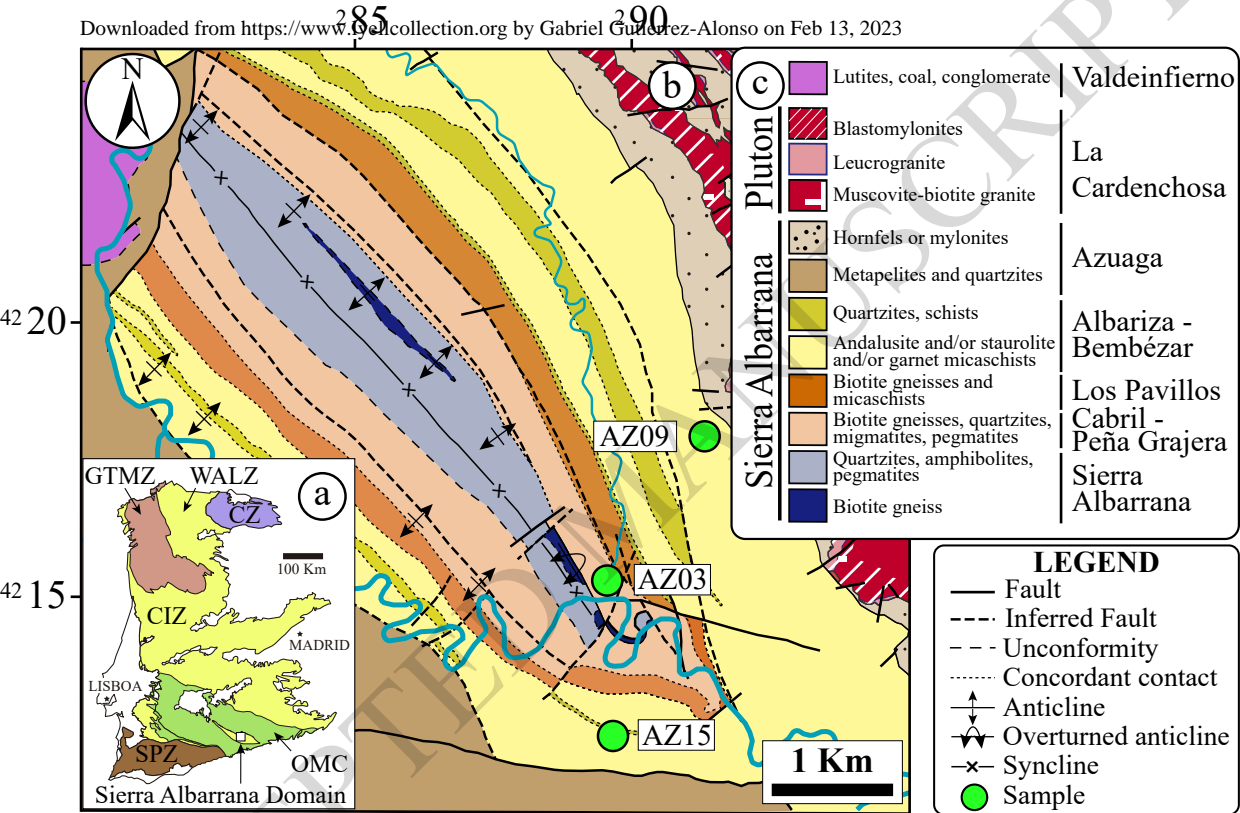


Fig. 1 a) Schematic geological map of the Iberian Massif showing the location of the study area (modified from Díez Fernández and Arenas, 2015); b) Geological map, and c) stratigraphic column from the SAD (simplified from Insúa et al., 1990). CZ – Cantabrian Zone, WALZ – West Asturian-Leonese Zone, CIZ – Central Iberian Zone, GTMZ – Galicia-Trás-os-Montes Zone, OMC – Ossa-Morena Complex, SPZ – South-Portuguese Zone

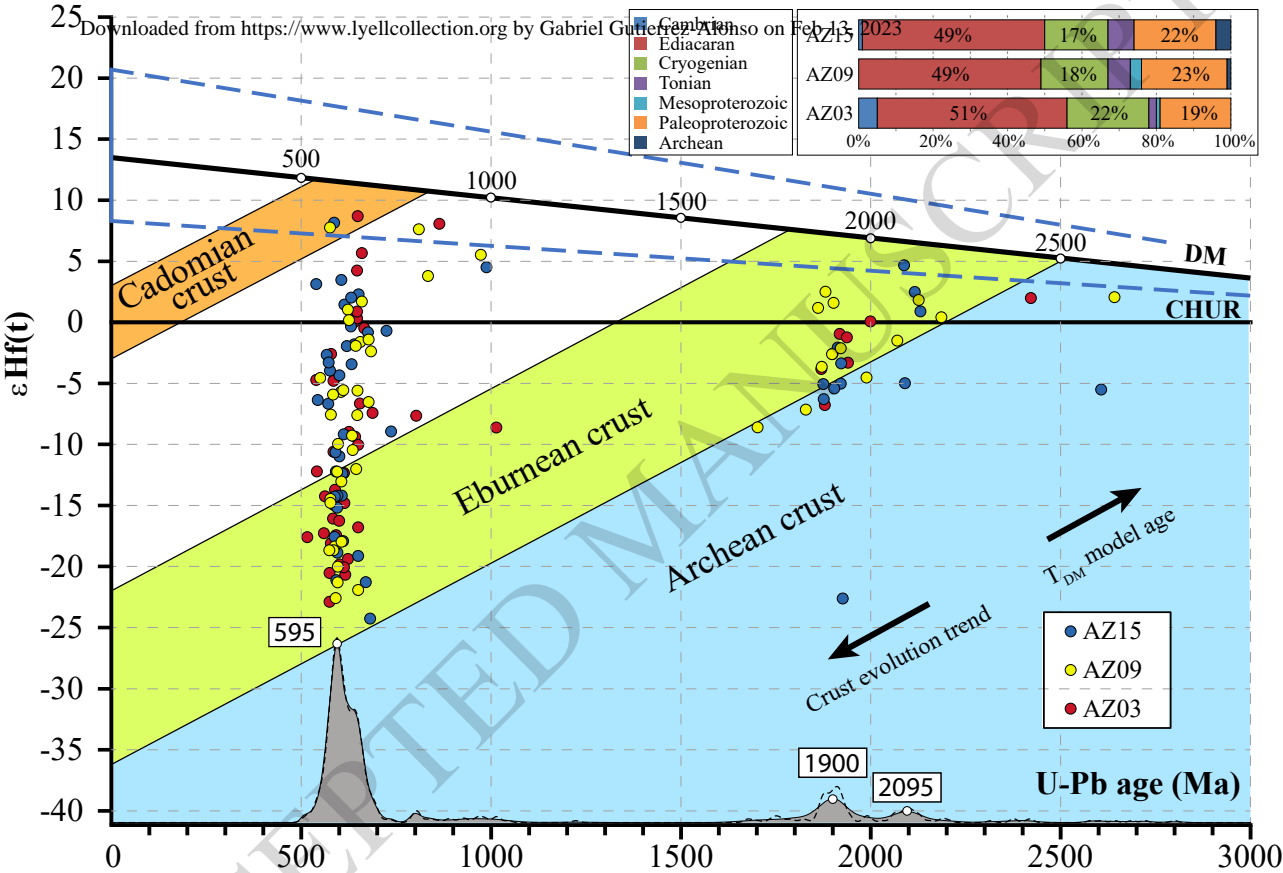


Fig. 2 Hf isotope evolution diagram showing SAD zircon data. Kernel Density Estimation of analysed zircon grains with Lu–Hf systematics is represented in grey. KDE and percentage of zircon populations bar (top right) taken from Solís-Alulima et al. (2022). CHUR – Chondritic uniform reservoir; DM – depleted mantle

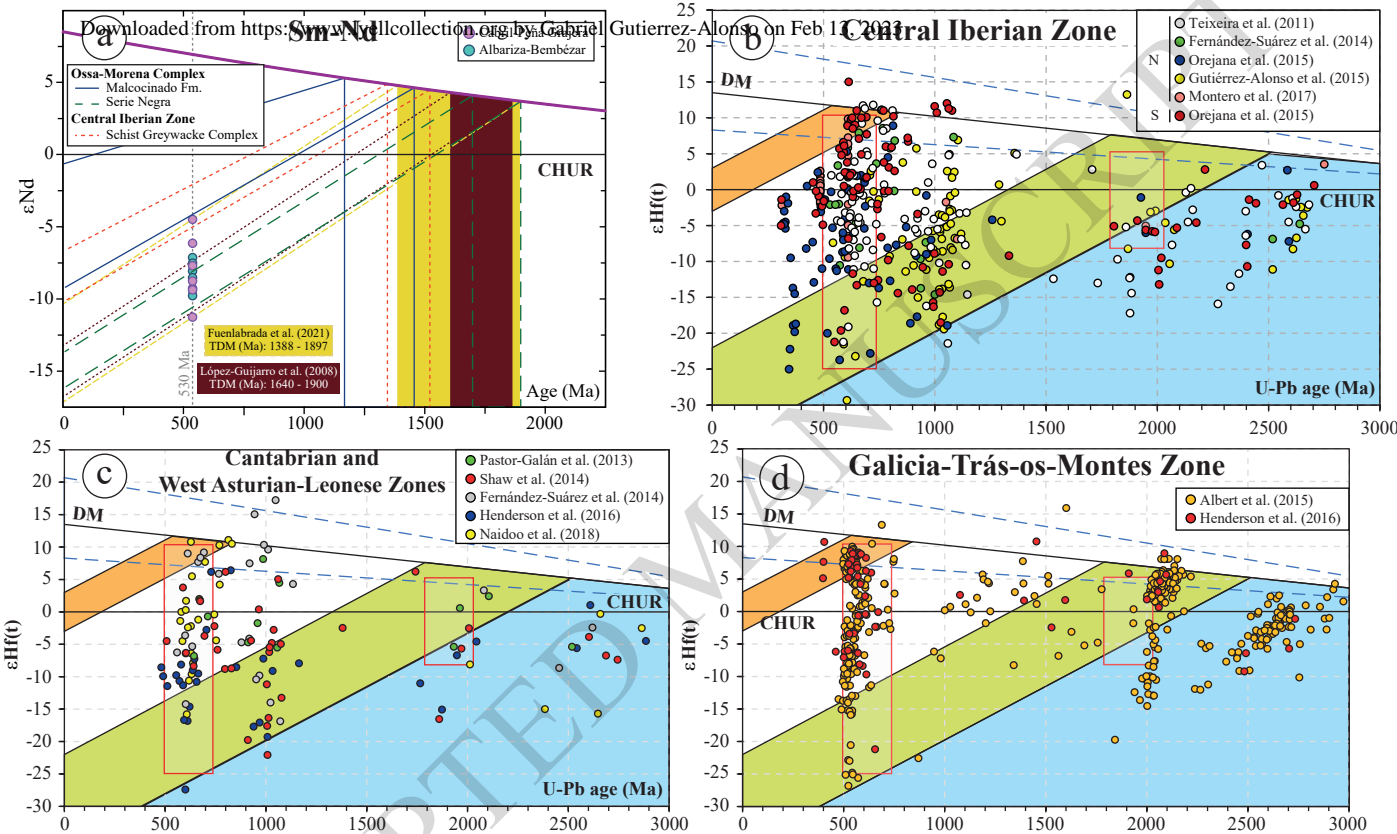


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Table 1

Zone	Sample	Formation	Reference
Central Iberian	EV-V	Carrazeda de Ansiães area (N)	Teixeira et al., 2011
	Malc1	Sabugal area (N)	Fernández-Suarez et al., 2014
	OD4	Monterrubio Formation	
	79	Talavera (N)	Orejana et al., 2015
	31-32	Guadarrama (N)	
	66-67-90-94	Schist Greywacke Complex (SGC) (S)	
	G7	Aljibe Quartzite	Gutiérrez-Alonso et al., 2015
	laz32	Base Quartzite Formation	
R-V	Ollo de Sapo	Montero et al., 2017	
Cantabrian	pg14	Formigoso Formation	Pastor Galán et al., 2013
	CZ02	Armorican Quartzite	Shaw et al., 2014
	OD5	Allande Gp.	Fernández-Suarez et al., 2014
	ACO-12-57	Oville Formation	Henderson et al., 2016
	M15-SAL15	Mora Fm. - Narcea Group	Naidoo et al., 2018
Galicia-Trás-os-Montes	GCH-07-09-10-11-12	Cariño Gneiss	Albert et al., 2015
	14-01, 02	Carreiro Shear Zone - Órdenes Complex	Henderson et al., 2016