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The Variscan basement in the western shoulder of the Lusitanian Basin (West Iberian Margin). Insights from detrital-zircon geochronology of Jurassic strata

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Abstract: There is no consensus about the geological nature of the westernmost portion of the Iberian Massif. In the present research, the detrital zircon U-Pb signatures of Jurassic strata of the Lusitanian Basin, known to be west-sourced, are combined with published U-Pb data for the Precambrian-Palaeozoic basement and the Lusitanian Basin units to better understand this poorly exposed portion of the Iberian Massif. Cryogenian to Ediacaran ages prevail in a northern Upper Jurassic unit, while Lower and Upper Jurassic rocks in southern locations yield mostly Carboniferous to upper Permian zircons. These age results, coupled with their respective U/Th ratios, suggest that the basin covers two distinct terranes of the Iberian Massif. Another noteworthy feature of west-derived deposits is the abundance of <310 Ma ages. It is proposed that a combination of crustal thinning in the West Iberian Margin with regional eastward basement tilt, favoured the enrichment of relatively young zircon in the western shoulder of the basin relative to its eastern margin. The detrital zircon age signatures also reveal a middle to late Permian thermal event in restricted areas, which is probably associated with the oldest stages of Alpine extension in West Iberia.

Keywords: Detrital zircon geochronology, Provenance, Jurassic, Berlengas Block, West Iberian Margin

1 Introduction

Three major tectono-stratigraphic units with Gondwana affinity (Galicia — Trás-os-Montes Zone, GTMZ), Central Iberian Zone, CIZ) and Ossa Morena Zone, OMZ) and one unit with Avalonian affinity (South Portuguese Zone, SPZ) crop out in the western portion of the Iberian Massif (e.g., Quesada 1991, Simancas et al. 2019). The rocks that are exposed to the west of the Porto-Tomar Fault Zone (PTFZ), both in the Iberian mainland and in the Berlengas Archipelago, have been assigned to different geotectonic units. Classic perspectives consider that they are part of the OMZ (Julivert et al. 1974; Ribeiro et al. 1990; Oliveira et al. 1992). Recently, however, it was proposed that the PTFZ separates the autochthonous or parautochthonous units of the CIZ and OMZ from a western crustal block called Finisterra Terrane, which includes the Berlengas Archipelago (Ribeiro et al. 2007; Moreira et al. 2019). Others proposed a simplification by merging the OMZ and GTMZ in a single unit and assigning the region to the west of the PTFZ to the SPZ (Díez-Fernández and Arenas 2015, Arenas et al. 2016, Díez Fernández et al. 2016). Tectonic models for the Variscan-Alleghanian orogen necessarily depend on possible stratigraphic assignments for the westernmost part of the Iberian Massif.

Sediment composition provides a broad picture of basement units that were exposed at the time of formation of depositional sequences, complementing what can be acquired from the direct investigation of possible source-rock units. Where basement exposures are scarce or difficult to access, sedimentary deposits can offer the best way to investigate the geological nature of regional crustal blocks. In addition, the infill of a sedimentary basin is likely able to reveal a history of exhumation, including rock units placed in upper crustal levels that are no longer available for direct investigation (Dickinson 1985, Garzanti 2016). Detrital zircon-age signatures prove to be an excellent tool when attempting to reconstruct the exhumation history of orogenic chains (e.g., Bernet et al. 2006, Gehrels 2014, Wang et al. 2016). Despite the uncertainties regarding zircon productivities, which necessarily depend on source rock composition (Rino et al.

2004, Moecher and Samson 2006, Hawkesworth et al. 2013), and the climatic and orographic setting that, by influencing clastic supply, also affect age signatures (Malusà and Garzanti 2019), the detrital zircon record of sedimentary units helps to understand the geological nature of their source terranes.

It has been considered that the Berlengas Block was the source area for several Lower to Upper Jurassic formations exposed onshore of the westernmost sector of the Lusitanian Basin (e.g., Wright and Wilson 1984, Guéry et al. 1986, Wilson 1989, Duarte 1997, Pena dos Reis et al. 1996, 2000, Ravnås et al. 1997, Barata et al. 2021). The present investigation is focused on the detrital-zircon age signature of a selection of Jurassic units enriched in siliciclastic components with that provenance. These geochronological data provide precious information about the basement rocks exposed at the time of the Lusitanian Basin infill. The geology of the western part of the Iberian Massif is crucial for the understanding of the evolution of West Europe and its conjugate margin in North America since the time of Pangea amalgamation.

2 The Lusitanian Basin

2.1 Tectonic framework

During the Triassic to Jurassic, the Lusitanian Basin (LB) overlies the Iberian Massif between the PTFZ, to the east, and the Berlengas Block, to the west (Fig. 1). The western part of the Iberian Massif comprises a series of upper Neoproterozoic to Paleozoic metasedimentary successions along with magmatic rocks and metamorphic units with igneous prototith, including pre-Variscan (mainly upper Ediacaran and Cambrian-lower Ordovician) and Variscan to post-Variscan (i.e., Upper Devonian–Permian) (e.g., Oliveira et al. 1992, Simancas 2019). Depending on regional models for the tectono-stratigraphy of the Iberian Massif, the Triassic and Jurassic infill of the LB stands either on the OMZ (Oliveira et al. 1992), the Finisterra Terrane (Ribeiro et al. 2007, Moreira et al. 2019), or units akin to the Avalonia terrane, including the SPZ (Simancas et al. 2005, Díez Fernández and Arenas 2015, Arenas et al. 2016, Díez Fernández et al. 2016).

The Berlengas Archipelago (Fig. 1), with the Berlengas and Farilhões groups and the Estelas islets, is the westernmost outlier of the Iberian Massif (Freire de Andrade 1937, Vanney and Mougenot 1981). It is a horst block (hereafter referred to as the Berlengas Block) separating the LB from an external domain of the West Iberian Margin that includes the Peniche Basin (e.g., Alves et al. 2006, Terrinha et al. 2019). The archipelago's rocks include granites in Berlenga and Estelas, and migmatites, gneisses and micaschists in Farilhões. A few geochronological studies have been presented for the archipelago. The Berlengas granite yields zircon and monazite dated by ID-TIMS at 305.2 Ma (Valverde Vaquero et al. 2011). However, previous studies, based on $^{87}Rb/^{86}Sr$ data for whole rock, pointed to a younger Permian age (280 ± 15 Ma; Priem et al. 1965). Monazite retrieved from a two-mica granite of Farilhões provided a concordia age of 376 ± 3 Ma (Valverde Vaquero et al. 2011).

After the Variscan cycle, which completed the assemblage of the Iberian Massif, an extensional phase, related to final Variscan orogenic collapse, started during the early Permian in eastern and central Iberia (e.g., Arche and López-Gómez 1996, Arche et al, 2004, López-Gómez et al. 2019, 2021). In western Iberia, the oldest units related to Pangea break-up are dated as Triassic (Palain 1976, Pinheiro et al. 1996, Soares et al. 2012). Mesozoic rifting climaxed during the Oxfordian (Late Jurassic) (Wilson et al. 1989, Pena dos Reis et al. 1996, 2000, Leinfelder and Wilson 1998, Alves et al. 2002, 2006, Pereira et al. 2017) and was associated with the formation of N-S trending extensional basins, namely the Lusitanian and Peniche basins at mid latitudes of west Iberia (Alves et al. 2006, Terrinha et al. 2019). It is usually considered that the Mesozoic evolution of the west Iberia margin was controlled by four main tectono-stratigraphic phases (Wilson et al. 1989): (1) Middle(?)/Late Triassic to Callovian; (2) middle Oxfordian to Berriasian; (3) late Berriasian to late Aptian; (4) late Aptian to early Campanian. During the Triassic, the eastern border of the LB was controlled by the reactivation of the PTFZ (Pinheiro et al.

1996, Soares et al. 2012). The uplift of the Berlengas Block, limiting the basin to the west, is indicated by west-derived clastic deposits in the uppermost Lower Jurassic succession (Toarcian; e.g., Wright and Wilson 1984, Duarte 1997, Barata et al. 2021), but was probably also active during the Triassic. Later, the Late Jurassic rifting created several sub-basins separated by crustal faults within the LB (e.g., Wilson 1979, Alves et al 2003b, Taylor et al. 2014), with the continental breakup between Iberia and Newfoundland being achieved during the middle Aptian (Dinis et al. 2008, Stapel et al. 1996, Rasmussen et al. 1998, Alves et al. 2002, 2003a).

2.2 Stratigraphy

The LB shows a locally > 5-km-thick sedimentary infill, comprising siliciclastic and carbonate units deposited in alluvial fan to hemipelagic environments and dated between the Middle(?)/Upper Triassic and the Early Cretaceous, which includes at least three first-order sequences bounded by regional unconformities (UBS; unconformity-bounded sequences): Middle(?)/Upper Triassic-Callovian, middle Oxfordian-lower Berriasian, and Berriasian-lower Aptian (e.g., Wilson et al. 1989, Alves et al. 2002, Azerêdo et al. 2003). The first two UBS encompass the stratigraphic intervals studied here.

The UBS1 starts with mainly Upper Triassic to lowermost Jurassic clastic deposits of variable grain-size deposited in alluvial fan, fluvial, and lacustrine environments (Palain 1976, Soares et al. 2012). This succession is followed by Lower and Middle Jurassic dolomites, carbonate-ramp marls, marly limestones and limestones, locally with significant siliciclastic component (e.g., Wright and Wilson 1984, Duarte 1997, Azerêdo 1998, Azerêdo et al. 2003, Duarte et al. 2012, Soares et al., 2012). The UBS2 (middle Oxfordian to lowermost Berriasian) reflects the independent evolution of sub-basins created during the Late Jurassic rifting. It comprises fresh-water to brackish carbonate units at the base, followed by marine carbonates and deltaic to alluvial-fan siliciclastic deposits (e.g., Leinfelder and Wilson 1998, Pena dos Reis et al. 1996, 2000, Rasmunssen et al. 1998).

Most of the LB infill documents a dominant siliciclastic source from the eastern margin of the LB. However, in the westernmost part of central mainland Portugal, several Jurassic and Cretaceous lithostratigraphic units record a western siliciclastic supply derived from the Berlengas Block. This provenance is supported by paleocurrent indicators, clast composition, and interpreted paleogeography (e.g., Hill 1989, Ravnås et al. 1997, Pena dos Reis et al. 2000).

3 Materials and methods

3.1 Studied successions

Three Jurassic units exposed along the western limit of the onshore LB and displaying clear evidence of supply from its western shoulders were selected for the present study (Figs. 1-3). This set of units provides unique conditions to indirectly asses the geological nature of the Berlengas Block. Cretaceous successions with paleocurrents indicating feeding systems from the west were not considered because the probability of including sediment recycled from the eastern flank of the basin is expected to increase in younger deposits. On the other hand, Triassic siliciclastic deposits are exposed only in the eastern basin margin, where they are associated with short-distance supply from the east (Palain 1976, Soares et al. 2012, Dinis et al. 2018). Samples for zircon geochronology were retrieved from the Lower Jurassic Cabo Carvoeiro Formation and the Upper Jurassic Abadia and Alcobaça formations.

The sampled Cabo Carvoeiro 2 member of Cabo Carvoeiro Fm. crops out in Praia do Abalo (LJ-Ab; Figs. 1-3), where it is part of a thick carbonate succession exclusively observed in the Peniche peninsula (e.g., Wright and Wilson 1984, Duarte 1997, Duarte et al. 2017, Barata et al. 2021). This member is a marly-dominated unit (~ 25 m thick), well dated as early Toarcian by ammonites (Duarte and Soares 2002), that includes sandy limestones, feldspatho-quartzose calcareous sandstones and microconglomerates, all of them showing typical turbidite features (e.g., Wright and Wilson 1984, Duarte 1997). Laterally, towards the east of the basin, the Cabo Carvoeiro Formation passes to hemipelagic marl-limestone alternations deposited in a carbonate ramp setting (S. Gião Fm.; Duarte 1997, Duarte and Soares 2002).

The Alcobaça Fm. comprises marginal-marine, brackish and continental carbonates and siliciclastic rocks. This unit is classically considered to span most or even all the Kimmeridgian (e.g., Rasmussen et al 1998). Based on ammonite stratigraphy, Marques et al. (1992) considered that it can reach the lower Tithonian, whereas Schneider et al. (2009), based on Sr isotopes, proposed a latest Oxfordian to late Kimmeridgian age. A meter-thick sandstone bed within a mud-dominated succession deposited in fluvio-deltaic environment that is exposed in Praia da Gralha (São Martinho do Porto) was selected for detrital zircon geochronology (Figs. 1-3).

The Abadia Fm. is considered to be a basinal lateral equivalent, to the south, of the Alcobaça Fm. (Rasmussen et al 1998, Pena dos Reis et al 2000, Schneider et al 2009, Kullberg and Rocha 2014). This unit comprises deep-water marls and turbiditic sandstones, along with coarse-grained submarine deposits. Paleocurrent data and depositional architecture of marine sandstone-conglomerates of the Abadia Fm. and transition to overlying fluvial deposits of the Lourinhã Fm. are robust evidence of provenance from the west (Ellwood 1987, Hill 1989, Ravnås et al. 1997). A 3 m thick sandstone bed from the upper part of Abadia Fm. exposed in Praia da Amoreira beach was selected for this study (Figs. 1-3). These deposits belong to a succession of steeply inclined sandstone intercalated with heterolithic beds interpreted as either foreset-bottomset units of a prograding fan delta (Ravnås et al. 1997) or as the infill of a submarine channel (Ellwood 1987).

3. Analytical and statistical procedures

Separation of zircon grains was carried out at the Earth Sciences Department of University of Coimbra. Samples were manually disintegrated, and the fractions finer than 0.038 mm and coarser than 0.5 mm were removed through wet sieving. Heavy liquids (sodium polytungstate and methylene iodide) and a Frantz isodynamic magnetic separator were used to obtain the zircon concentrates. An aliquot of heavy-mineral concentrates before the magnetic separation was mounted on glass slides and analyzed under the petrographic microscope. U-Pb ages were determined at the London Geochronology Centre using an Agilent 7700× LA-ICP-MS (laser ablation-inductively coupled plasma-mass spectrometry) system, employing a NWR193 Excimer Laser operated at 11 Hz with a 20 µm spot size and 2.5–3.0 J/cm^2 fluence.

Data reduction was performed using GLITTER 4.4.2 software (Griffin et al. 2008). We used ^{206}Pb/^{238}U and ^{207}Pb/^{206}Pb ages for zircons younger and older than 1100 Ma, respectively. No common Pb correction was applied. The original data was screened through these discordance filters and grains with >5−15% age discordances were discarded. Data was plotted as Kernel density estimations with different bandwidths using *DensityPlotter* software (Vermeesch 2012). Multidimensional Scaling (MDS) was adopted to compare the obtained age results with possible source terranes. MDS is a multivariate technique that takes a dissimilarity matrix as input to obtain a map where similar samples plot close together and dissimilar samples plot far apart. To perform the MDS with detrital zircon age distribution, a dissimilarity matrix was constructed using the Kolmogorov-Smirnov statistic (Vermeesch 2013).

4 Results

4.1 Heavy minerals

Heavy-mineral concentrates obtained from the lower Toarcian turbidite of the Cabo Carvoeiro Fm. (LJ-Ab) include abundant chlorite and significant amounts of rock fragments and light minerals. The translucent heavy mineral assemblage yields mainly the durable minerals zircon and tourmaline. The Kimmeridgian beds provided substantially different heavy-mineral assemblages. In the northern sample from the Alcobaça Fm., staurolite, garnet and dravitic tourmaline dominate the assemblage. The southern sample (from the Abadia Fm.) yielded zircon and subordinate tourmaline, garnet, and monazite.

4.2 Detrital zircon U-Pb data

Samples LJ-Ab (lower Toarcian, Cabo Carvoeiro Fm.) and UJ-Am (Kimmeridgian, Abadia Fm.) yielded similar zircon-age signatures (Fig. 4). The zircon grains are mainly Carboniferous-Permian (85%, ranging 349-254 Ma, in LJ-Ab; 80%, ranging 339-276 Ma, in UJ-Am). The KDE spectrum for the Toarcian sample (LJ-Ab) reveals two peak maxima at approximately 305 Ma and 292 Ma and a secondary peak at 264 Ma; the Kimmeridgian-Tithonian sample (UJ-Am) yields a sharp peak at 295 Ma. Cryogenian to Ediacaran zircons, ranging in age 692-556 Ma, occur in secondary amounts (17% in LJ-Ab; 13 % in UJ-Am) and both samples gave one Middle Triassic grain (243 Ma in LJ-Ab; 230 Ma in UJ-Am).

The Kimmeridgian bed from Alcobaça Fm. (UJ-Gr) is dominated by Cryogenian to Ediacaran grains (83 % ranging 673-543 Ma), with frequency peaks at 608, 595, 580, and 554 Ma (Fig. 4). Cambrian-Silurian (7%, ranging 541-456 Ma), Paleoproterozoic (3%, ranging 541-456 Ma Ma) and Carboniferous-Permian (342 Ma and 273 Ma) grains are subordinate to minor.

Th/U ratios obtained during laser ablation range 0.05 - 1.15 (Fig. 5). Cryogenian-Ediacaran zircons tend to yield higher Th/U than Carboniferous-Permian grains. Th/U ratios for the majority of grains of this age retrieved from UJ-Am (Kimmeridgian, Abadia Fm.) are relatively low, whereas those from LJ-Ab (Toarcian, Carbo Carvoeiro Fm.) are more variable.

5 Discussion

5.1. Zircon sources and corresponding terranes

The late Cryogenian-Ediacaran population, well represented in UJ-Gr and prevalent in many Mesozoic units of West Iberia (Dinis et al. 2016, 2018, Pereira et al. 2016, 2017), is also dominant in most basement units of West Iberia (Linnemann et al. 2008, Talavera et al. 2012, Pereira et al. 2012a, 2012b, 2014, Rodrigues et al. 2015). These ages correspond with the Pan-African to Cadomian orogenies, two periods of crustal growth that overlap in northern Gondwana realms (Murphy and Nance 1991, Nance and Murphy 1994, Linnemann et al. 2008).

The oldest peak within the Carboniferous-Permian age population (~315 Ma in UJ-Am; ~305 Ma in LJ-Ab) corresponds to the paroxysmal stages of Variscan collisional magmatism in Iberia, which started at ~350 Ma and persisted for almost the entire Carboniferous (Dias et al. 1998, Fernández-Suárez et al. 2000, Jesus et al. 2007, Hildenbrand et al, 2021). Magmatic rocks of this age are also well represented in the conjugate West Atlantic margin in the easternmost terranes of the Appalachian Orogen (MacLean et al. 2003, Pe-Piper et al. 2010). Zircon grains potentially derived from those primary sources are common in Mesozoic units of the West Iberian Margin (Dinis et al. 2016, 2018, Pereira et al. 2016, 2017) and of its Canadian conjugate margin (Lowe et al. 2011, Hutter and Beranek 2020). The ~290-295 Ma peaks identified in southern samples (LJ-Ab and UJ-Am) are genetically linked to post-Variscan magmatism coeval to the post-orogenic collapse of the Variscan chain (Marques et al. 2002, López-Gómez et al. 2019, 2021, Hildenbrand et al 2021) or the buckling of the Cantabrian orocline (Gutiérrez-Alonso et al. 2004, 2011, Merino-Tomé et al. 2009, Pastor-Galán et al. 2013). Similar zircons ages are common in some Cretaceous strata of the West Iberian Margin (Dinis et al. 2016) and occur in the Permian Viar Basin formed ~350 km SE-ward, where they were either exhumed from high crustal levels or extruded during volcanic events (Dinis et al. 2018).

The secondary middle Permian peak at ~264 Ma (exclusive of LJ-Ab) is notably younger than the main phases of Pangea amalgamation. These zircons, along with the rare Middle Triassic grains, are probably associated with subsequent Pangea break-up in West Iberia. Grains of comparable age were identified in Triassic (Dinis et al. 2018) and Cretaceous (Dinis et al. 2016) lithostratigraphic units of the LB, being ascribed to mafic magmatism during early stages of extension (Gardien and Paquette 2004, Orejana et al. 2008).

To better link the obtained age distributions with possible source terranes, an MDS was performed. Taking as input the entire dataset obtained for the three Jurassic units and age results published elsewhere for west Iberia basement units, the MDS map separates LJ-Ab (lower Toarcian, Cabo Carvoeiro Fm.) and UJ-Am (Kimmeridgian, Abadia Fm.) from all basement units, and plots UJ-Gr (Kimmeridgian, Alcobaça Fm.) close to OMZ and CIZ (Fig. 6). The field for SPZ is wider, reflecting high compositional variability mainly determined by the proportion of Variscan grains, which are abundant in some units but rare or absent in others (Pereira et al. 2012b, 2014, Rodrigues et al. 2015). The isolated location of LJ-Ab and UJ-Am in the MDS map is explained by their enrichment in relatively young grains.

The variability in zircon age distributions for each major tectono-stratigraphic unit of the Iberian basement and the similarities among them do not allow conclusive interpretations regarding the basement of the LB. The zircon age signatures, however, do not indicate that they belong to a Finisterra Terrane (Ribeiro et al. 2007, Moreira et al. 2019). The west-derived deposits of the LB lack zircon ages that occur in metamorphic units ascribed to the Finisterra terrane, such as Ordovician (Sousa et al. 2014, Moreira et al. 2019) and Upper Silurian-Early Devonian and Early Devonian-Mississippian (Almeida et al. 2014). These ages are represented in sedimentary successions formed close to the PTFZ (Dinis et al. 2012, 2018), along which most rock units assigned to the Finisterra Terrane are presently exposed. Mesoproterozoic zircons in the Pennsylvanian Buçaco Basin were also considered to be derived from the Finisterra Terrane (Moreira et al. 2019), but these ages are also missing in west-derived deposits of the LB. It can be alleged that, as the abovementioned age populations are not abundant in sedimentary deposits formed close to the PTFZ, the presence of a clearly dominant younger population in LJ-Ab and UJ-Am probably diluted the detrital fingerprint, making those ages common in Finisterra Terran harder to identify. However, they are also missing in UJ-Gr, which lacks the young age population.

5.2. Tectono-stratigraphic implications

At the latitude of Peniche and to the south, Variscan igneous rocks must have been extensively exposed in the western flank of the LB during the Jurassic stages of Pangea break-up. To the north, instead, they appear to be minor zircon suppliers. The different age signature in northern locations is ascribed to a scarcity of Variscan magmatic outliers or to dilution by other zircon sources. The heavy-mineral assemblage characterized by dominant garnet and staurolite supports a high-grade metamorphic provenance. Part of the Pan-African to Cadomian-aged zircons may be recycled from Triassic units deposited during the early stage of Pangea break-up, where this age population is frequently the most abundant (Pereira et al. 2016, 2017, Dinis et al. 2018).

A dyke-breccia in Peniche, close to the studied Cabo Carvoeiro Fm. at Praia do Abalo, includes granitic xenoliths that yield late Pennsylvanian-early Permian zircons (Pereira et al. 2020), suggesting that the LB developed on a crustal block with late and post-Variscan magmatic rocks. In the LB, the frequency of <310 Ma-aged zircons is a noteworthy feature of the signature of the studied west-derived strata. The late Paleozoic population identified in Triassic units of the Algarve and Alentejo basins, which were mainly sourced from the SPZ, is notably older (~330 Ma; Pereira et al. 2016; Dinis et al. 2018). Some Triassic rocks overlying the OMZ yield an only minor frequency peak <300 Ma (Dinis et al. 2018). For Cretaceous successions of the LB, late Paleozoic peaks tend to become younger upward, possibly due to the exhumation of progressively younger igneous rocks emplaced in the uplifted CIZ, but the maxima for Lower Cretaceous units are in general >300 Ma (Dinis et al. 2016). Only in stratigraphic units approximately 40 Ma younger than the youngest west-derived units presented here the late Paleozoic populations display major peaks at ~295-290 Ma.

In summary, in the LB, the late Paleozoic zircon-age population appears to be younger in successions mainly sourced from the west than in those sourced from the east. Such an age difference probably results from more extensive crustal thinning in the western margin than for inland Iberian regions, allowing for the emplacement of igneous rocks into upper-crustal levels. The Berlengas Block is presently placed in a necking sector between hyper-thinned and proximal realms of crustal margin (Stanton et al. 2016, Granado et al. 2021), but significant thinning would be necessary by early Permian. The 295-285 Ma interval was already proposed to be characterized by post-orogenic extension (Variscan orogenic collapse) in West Iberia and associated with the uplift of the CIZ relative to OMZ (Hildenbrand et al 2021). Additionally, a rapid exhumation of recently formed primary zircon sources in the western shoulder of the basin may have been triggered by the eastward tilting of the basin basement (Fig. 7). The geometry of the basement top, as recognized in several seismic lines (e.g., Alves et al 2006, Pereira et al 2017), is compatible with this possibility.

Further inferences can be drawn from Th/U ratios. Although this parameter even for single magmatic bodies can be widely variable, it has been used to assess temperatures of zircon crystallization and the felsic *vs.* intermediate character of the host rocks. Under equilibrium conditions, Th/U ratios tend to be higher in zircons formed at higher temperatures and in intermediate/mafic rocks than at lower temperatures and in granitic rocks (Xiang et al. 2011, Kirkland et al 2015). The discernible differences in Th/U suggest hotter conditions for the Permian zircons formed near Berlengas Archipelago than to the south (Fig. 5), which can be ascribed, for example, to crystallization in a crustal block with previously emplaced mafic rocks or in a specially thinned lithosphere. Regardless the actual explanation for the differences in Th/U ratios, these results, coupled with zircon ages, indicate that major basement boundaries were cut by the broadly N-S rift structures that control the western border of the LB (Fig. 7).

Conclusions

Detrital zircons contained in sedimentary rocks of the Lusitanian Basin with a western provenance yielded either dominant late Cryogenian to Ediacaran ages (Pan-African and/or Cadomian with peaks at 608-554 Ma) or Carboniferous to Permian ages (Variscan and post-Variscan, with peaks at 315-292 Ma). Differences in age signatures and zircon chemistry (Th/U ratios) indicate significant variability along basin-strike in exhumed basement rocks. A discernible peak at ~264 Ma reveals a middle to late Permian thermal event in restricted areas of West Iberia. Although rare, Middle Triassic zircon grains were identified in different regions of the Lusitanian Basin, suggesting that the Triassic rifting was then affecting wide western areas.

The detrital-zircon signatures of these west-derived strata do not allow a clear diagnosis about the geotectonic nature of the Lusitanian Basin basement. But suggest that: (1) the basin stands on different terranes of the Iberian Massif in its western edge; (2) the Lusitanian Basin developed after the collapse of the Variscan Orogen in an area characterized by recently emplaced igneous rocks (i.e., during the latest Pennsylvanian-Permian); (3) primary zircon sources were more extensively eroded from the western shoulders of the basin, probably due to a combination of crustal thinning and regional eastward basement tilt.

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References

Almeida N, Egydio Silva M, Fonseca PE, Bezerra MH, Basei M, Chaminé HI, Tassinari C (2014) Novos dados geocronológicos do Finisterra. Comunicações Geológicas 101:31-34

Alves TM, Gawthorpe RL, Hunt DH. Monteiro JH (2002) Jurassic tectono-sedimentary evolution of the Northern Lusitanian Basin (offshore Portugal), Mar. Pet. Geol. 19:727–754

Alves TM, Gawthorpe RL, Hunt DW, Monteiro JH (2003a) Post-Jurassic tectono-sedimentary evolution of the Northern Lusitanian basin (Western Iberian margin). Basin Res 15:227–250

Alves TM, Manuppella G, Gawthorpe RL, Hunt DW, Monteiro JH (2003b) The depositional evolution of diapir- and fault-bounded rift basins: Examples from the Lusitanian Basin (Offshore Portugal). Marine and Petroleum Geology 19:727–754

Alves TM, Moita C, Sandnes F, Cunha T, Monteiro JH, Pinheiro LM (2006) Mesozoic–Cenozoic evolution of North Atlantic continental-slope basins: The Peniche basin, western Iberian margin. AAPG Bulletin 90:31-60

Arche A, López-Gómez J (1996) Origin of the Permian-Triassic Iberian Basin, central-eastern Spain. Tectonophysics 266: 443–464

Arche A, López-Gómez J, Marzo M, Vargas H (2004) The siliciclastic Permian-Triassic deposits in Central and Northeastern Iberian Peninsula (Iberian, Ebro and Catalan Basins): A proposal for correlation. Geol. Acta 2: 305–320

Arenas R, Fernández RD, Pascual FJR, Martínez SS, Parra LMM, Matas J, ... Garcia-Casco A. (2016) The Galicia–Ossa-Morena Zone: proposal for a new zone of the Iberian Massif. Variscan implications. Tectonophysics 681:135-143

Azerêdo AC (1998). Geometry and facies dynamics of Middle Jurassic carbonate ramp sandbodies, West-Central Portugal. In: Wright V.P. and Burchette, T. (Eds.): Carbonate Ramps. *Geological Society of London*, Special Publications 149, 281-314.

Azerêdo AC, Duarte LV, Henriques MH, Manuppella G (2003) Da dinâmica continental no Triásico aos mares do Jurássico Inferior e Médio. Cadernos de Geologia de Portugal, Instituto Geológico e Mineiro

Barata J, Duarte LV, Azerêdo AC (2021) Facies types and depositional cyclicity of a Toarcian-Aalenian(?) carbonate-siliciclastic mixed succession (Cabo Carvoeiro Formation) in the Lusitanian Basin, Portugal. Journal of Iberian Geology. https://doi.org/10.1007/s41513-021-00163-2

Bernet M, van der Beek P, Pik R, Huyghe P, Mugnier JL, Labrin,E, Szulc A (2006) Miocene to recent exhumation of the central Himalaya determined from combined detrital zircon fission-track and U/Pb analysis of Siwalik sediments, western Nepal. Basin Research 18:393-412

Dias G, Leterrier J, Mendes A, Simões PP, Bertrand JM (1998) U-Pb zircon and monazite geochronology of post-collisional Hercynian granitoids from the Central Iberian Zone (northern Portugal). Lithos 45:349–369

Dickinson W R (1985) Interpreting provenance relations from detrital modes of sandstones. In Provenance of arenites (pp. 333-361). Springer, Dordrecht

Díez Fernández R, Arenas R (2015) The Late Devonian Variscan suture of the Iberian Massif: A correlation of high-pressure belts in NW and SW Iberia. Tectonophysics 654:96-100

Díez Fernández R, Arenas R, Pereira MF, Sánchez-Martínez S, Albert R, Parra LMM, ... Matas J (2016) Tectonic evolution of Variscan Iberia: gondwana–Laurussia collision revisited. Earth-Science Reviews 162:269-292

Dinis J, Rey J, Cunha PP, Callapez P, Pena dos Reis R (2008) Stratigraphy and allogenic controls of the western Portugal Cretaceous: an updated synthesis. Cretaceous Research 29:772-780. doi: 10.1016/j.cretres.2008.05.027

Dinis PA, Dinis J, Tassinari C, Carter A., Callapez P, Morais M (2016) Detrital zircon geochronology of the Cretaceous succession from the Iberian Atlantic Margin: palaeogeographic implications. International Journal of Earth Sciences 105:727-745

Dinis PA., Fernandes P, Jorge RC, Rodrigues B, Chew DM, Tassinari CG (2018) The transition from Pangea amalgamation to fragmentation: constraints from detrital zircon geochronology on West Iberia paleogeography and sediment sources. Sedimentary Geology 375:172-187

Dinis P, Anderson T, Machado G, Guimaraes F (2012) Detrital zircon U–Pb ages of a late-Variscan Carboniferous succession associated with the Porto–Tomar shear zone (West Portugal): Provenance implications. Sedimentary Geology 273–274:19–29

Duarte LV (1997). Facies analysis and sequential evolution of the Toarcian-Lower Aalenian series in the Lusitanian Basin (Portugal). Comunicações do Instituto Geológico e Mineiro 83*:* 65–94.

Duarte LV, Silva RL, Félix F, Comas-Rengifo MJ, da Rocha RB, Mattioli E, et al. (2017) The Jurassic of the Peniche Peninsula (Portugal): scientiic, education and science popularization relevance. Revista de la Sociedad Geológica de España 30: 55–70.

Duarte LV, Silva RL., Mendoça Filho JG, Poças Ribeiro N., Chagas RBA (2012) High-resolution stratigraphy, palynofacies and source rock potential of the Água de Madeiros Formation (Lower Jurassic), Lusitanian Basin, Portugal. Journal of Petroleum Geology 35, 105-126

Duarte LV, Soares, AF (2002) Litostratigrafia das séries margo-calcárias do Jurássico Inferior da Bacia Lusitânica (Portugal). Comunicações do Instituto Geológico e Mineiro 89: 135–154

Ellwood PM (1987) Sedimentology of the Upper Jurassic Abadia formation and its equivalents, Lusitanian Basin, Portugal. PhD Thesis, Open University, Milton Keynes, U.K. (unpublished)

Fernández-Suárez J, Dunning GR, Jenner GA, Gutiérrez-Alonso G (2000) Variscan collisional magmatism and deformation in NW Iberia: constraints from U-Pb geochronology of granitoids. Journal of the Geological Society 157:565–576

Fonseca P, Munhá J, Pedro J, Rosas F, Moita P, Araújo A, Leal N (1999) Variscan ophiolites and high-pressure metamorphism in southern Iberia. Ofioliti 24:259–268

Freire-de-Andrade C (1937) Os Vales Submarinos Portugueses e o Diastrofismo das Berlengas e da Estremadura. Memórias dos Serviços Geológicos de Portugal 5:1-35

Gardien V, Paquette JL (2004) Ion microprobe and ID-TIMS U–Pb dating on zircon grains from leg 173 amphibolites: evidence for Permian magmatism on the West Iberian margin. Terra Nova 16:226–231

Garzanti E (2016) From static to dynamic provenance analysis—Sedimentary petrology uUJ-Graded. Sedimentary Geology 336:3-13

Gehrels G (2014) Detrital zircon U-Pb geochronology applied to tectonics. Annual Review of Earth and Planetary Sciences 42:127-149

Granado C, Muñoz‐Martín A, Olaiz AJ, Fernández O, Druet M (2021) 3D crustal‐scale structure of the West Iberia margin: a novel approach to integrated structural characterization of passive margins. Marine Geophysical Research 42:10 https://doi.org/10.1007/s11001-021-09432-2

Griffin WL, Powell WJ, Pearson NJ, O'Reilly SY (2008) GLITTER: data reduction software for laser ablation ICP-MS. In Sylvester P (eds) Laser Ablation–ICP–MS in the Earth Sciences. Mineralogical Association of Canada Short Course Series 40, pp 204–207

Guéry F, Montenat C, Vachard D (1986) Evolution tectono-sedimentaire du bassin portugais au Mesozoique suivant la transversale de Peniche (Estremadure). Bulletin des centres de recherches exploration-Production Elf-Aquitaine 10:83-94

Gutiérrez-Alonso G, Fernández-Suárez J., Jeffries TE, Johnston ST, Pastor-Galán D, Murphy JB, Franco MP, Gonzalo JC (2011) Diachronous post-orogenic magmatism within a developing orocline in Iberia, European Variscides. Tectonics 30, TC5008. https://doi.org/10.1029/2010TC002845

Gutiérrez-Alonso G, Fernández-Suárez J, Weil AB (2004) Orocline triggered lithospheric delamination. Geological Society America Special Papers 383:121–130

Hawkesworth C, Cawood P, Dhuime B (2013) Continental growth and the crustal record: Tectonophysics 609:651–660, j.tecto.2021.228863

Hildenbrand A, Marques FO, Quidelleur X, Noronha F (2021) Exhumation history of the Variscan orogen in western Iberia as inferred from new KAr and 40Ar/39Ar data on granites from Portugal. Tectonophysics, 228863.

Hill G (1989) Distal alluvial fan sediments from the Upper Jurassic of Portugal: controls on their cyclicity and channel formation. J Geol Soc London 146:539–555.

Hutter AD, Beranek LP (2020) Provenance of Upper Jurassic to Lower Cretaceous synrift strata in the Terra Nova oil field, Jeanne d'Arc basin, offshore Newfoundland: A new detrital zircon U-Pb-Hf reference frame for the Atlantic Canadian margin. AAPG Bulletin, 104:2325-2349

Jesus A, Munhá J, Mateus A, Tassinari C, Nutman A (2007) The Beja layered gabbroic sequence (Ossa–Morena Zone, Southern Portugal): geochronology and geodynamic implications. Geodinamica Acta 20:139–157

Julivert M, Fontboté JM, Ribeiro A, Conde LEN (1974) Mapa Tectónico de la Península Ibérica y Baleares, Escala 1:1000.000. Memória Explicativa. Instituto Geologico y Minero de España, Madrid.

Kirkland CL, Smithies RH, Taylor RJM, Evans N, McDonald B (2015) Zircon Th/U ratios in magmatic environs. Lithos 212:397-414

Kullberg, J. C., & Rocha, R. B. (2014). O Jurássico Superior da Bacia Lusitaniana: importância da ligação entre litostratigrafia, cronostratigrafia e cartografia. I-O final do 2º episódio de rifting. Comunicações Geológicas, 101(Especial I), 459-462.

Kullberg JC, Rocha RB, Soares AF, Rey J, Terrinha P, Azerêdo AC, Callapez P, Duarte LV, Kullberg MC, Martins L, Miranda JR, Alves C, Mata J, Madeira J, Mateus O, Moreira M. (2013). A Bacia Lusitaniana: Estratigrafia, Paleogeograia e Tectonica. In R. Dias, A. Araujo, P. Terrinha, & J.C. Kullberg (Eds.), *Geologia de Portugal no contexto da Ibéria. Vol. II - Geologia Meso-cenozóica de Portugal* (pp. 195–347). Livr. Escolar Editora

Leinfelder RR, Wilson RCL (1998) Third-order sequences in an Upper Jurassic rift-related second-order sequence, central Lusitanian basin, Portugal. In: Graciansky PC, Hardenbol J, Jacquin T, Vail PR (eds) Mesozoic and cenozoic sequence stratigraphy of European basins, SEPM Spec Pub 60:507–525

Linnemann U, Pereira MF, Jeffries T, Drost K, Gerdes A (2008) Cadomian Orogeny and the opening of the Rheic Ocean: the diachrony of geotectonic processes constrained by LA-ICP-MS U–Pb zircon dating (Ossa-Morena and Saxo-Thuringian Zones, Iberian and Bohemian Massifs). Tectonophysics 461:21–43

López-Gómez, J, Martín-González F, Heredia N, De la Horra R, Barrenechea JF, Cadenas P, Juncal M, Diez JB, Borruel-Abadia V, Pedreira D, García-Sansegundo J, Farias P, Galé C, Lago M, Ubide T, Fernández-Viejo G, Gand G (2019) New lithostratigraphy for the Cantabrian Mountains: A common tectonostratigraphic evolution for the onset of the Alpine cycle in the W Pyrenean realm, N Spain. Earth Sciences Review 188:249–271

López-Gómez J, De la Horra R, Barrenechea JF, Borruel-Abadía V, Martín-Chivelet J, Juncal M, Martín-González F, Heredia F, Diez JB, Buatois LA (2021) Early Permian during the Variscan Orogen Collapse in the equatorial realm: insights from the Cantabrian Mountains (N Iberia) into climatic and environmental changes. International Journal of Earth Sciences. doi.org/10.1007/s00531-021-02020-0

Lowe DG, Sylvester PJ, Enachescu ME (2011) Provenance and paleodrainage patterns of Upper Jurassic and Lower Cretaceous synrift sandstones in the Flemish Pass Basin, offshore Newfoundland, east coast of Canada. AAPG Bulletin 95:1295–1320

MacLean NJ, Barr SM, White CE, Ketchum JW (2003) New U-Pb (zircon) age and geochemistry of the Wedgeport Pluton, Meguma terrane, Nova Scotia. Atlantic Geology 39:239–253

Malusà MG., Garzanti E (2019) The sedimentology of detrital thermochronology. In Fission-Track Thermochronology and its Application to Geology, pp. 123-143.. Springer, Cham.

Marques B, Oloriz F, Caetano PS, Rocha RB, Kullberg JC (1992) Upper Jurassic of the Alcobaça Region. Stratigraphic Contributions. Comunicações dos Serviços Geológicos de Portugal 78:63-69

Marques FO, Mateus A, Tassinari C (2002) The Late-Variscan fault network in central–northern Portugal (NW Iberia): a re-evaluation. Tectonophysics 359:255-270

Merino-Tomé O, Bahamonde JR, Colmenero JR, Heredia N, Villa E, Farias P (2009) Emplacement of the Cuera and Picos de Europa imbricate system at the core of the Ibero-Armorican arc (Cantabrian Zone, N Spain): new precisions concerning the timing of arc closure. Geological Society of America Bulletin 121:729–751

Moecher DP, Samson SD (2006) Differential zircon fertility of source terranes and natural bias in the detrital zircon record: Implications for sedimentary provenance analysis. Earth and Planetary Science Letters 247:252-266

Moreira N, Romão J, Dias R, Ribeiro A., Pedro J (2019) The Finisterra-Léon-Mid German Cristalline Rise Domain; Proposal of a New Terrane in the Variscan Chain. In The Geology of Iberia: A Geodynamic Approach (pp. 207-228). Springer, Cham.

Murphy JB, Nance RD (1991) Supercontinent model for the constraining character of Late Proterozoic orogenic belts. Geology 19:469–472

Nance RD, Murphy JB (1994) Contrasting basement isotopic signatures and the palinspatic restoration of peripheral orogens: example from the Neoproterozoic Avalonian–Cadomian belt. Geology 22:617–620

Oliveira JT, Pereira E, Ramalho M, Antunes MT, Monteiro JH (1992) Carta geológica de Portugal à escala 1/500000, 5a edição (coords.). Serviços Geológicos de Portugal, Lisboa

Orejana D, Villaseca C, Billstrom K, Paterson BA (2008) Petrogenesis of Permian alkaline lamprophyres and diabases from the Spanish Central System and their geodynamic context within western Europe. Contrib Miner Petrol 156:457–500

Palain C (1976) Une série détritique terrigène les “Grès de Silves”: Trias et Lias inférieur du Portugal. Mem. Serv. Geol. Portugal 25:1–377.

Pastor-Galán D, Gutiérrez-Alonso G, Murphy JB, Fernández-Suárez J, Hofmann M, Linnemann U (2013) Provenance analysis of the Paleozoic sequences of the northern Gondwana margin in NW Iberia: passive margin to Variscan collision and orocline development. Gondwana Research 23:1089–1103

Pe-Piper G, Kamo SL, McCall C (2010) The German Bank pluton, offshore SW Nova Scotia: Age, petrology, and regional significance for Alleghanian plutonism. Geological Society of America Bulletin 122:690–700

Pena dos Reis R, Cunha PP, Dinis JL, Trincão PR (2000) Geologic evolution of the Lusitanian Basin (Portugal) during the Late Jurassic. GeoResearch Forum, Transtec Publications, Zurich, vol. 6; 345-356

Pena dos Reis R, Dinis J, Cunha PP, Trincão P (1996) Upper Jurassic sedimentary infill and tectonics of the Lusitanian Basin (Western Portugal). In Jurassic Research, Editor: A.C. Riccardi. GeoResearch Forum, Transtec Publications, Zurich, vols. 1-2:377-386

Pereira MF, Chichorro M, Johnston ST, Gutiérrez-Alonso G, Silva JB, Linnemann U, Hofmann M, Drost K (2012b) The missing Rheic Ocean magmatic arcs: provenance analysis of Late Paleozoic sedimentary clastic rocks of SW Iberia. Gondwana Res 3–4:882–891

Pereira MF, Linnemann U, Hofmann M, Chichorro M, Solá AR, Medina J, Silva JB (2012a) The provenance of Late Ediacaran and Early Ordovician siliciclastic rocks in the

Southwest Central Iberian Zone: constraints from detrital zircon data on northern Gondwana margin evolution during the late Neoproterozoic. Precambr Res 192–195:166–189

Pereira MF, Gama C, Silva JB, da Silva ÍD (2020) Age of the basement beneath the Mesozoic Lusitanian Basin revealed by granitic xenoliths from the Papôa volcanic breccia (West Iberia). Geologica Acta 18:1-14

Pereira MF, Ribeiro C, Vilallonga F, Chichorro M, Drost K, Silva JB, Albardeiro L, Hofman M, Linnemann U (2014) Variability over time in the sources of South Portuguese Zone turbidites: evidence of denudation of different crustal blocks during the assembly of Pangaea. International Journal of Earth Sciences 103:1453-1470

Pereira MF, Gama C, Chichorro M, Silva JB, Gutiérrez-Alonso G, Hofmann M, Linnemann U, Gartner A (2016) Evidence for multi-cycle sedimentation and provenance constraints from detrital zircon U–Pb ages: Triassic strata of the Lusitanian basin (western Iberia). Tectonophysics 681:318–331

Pereira MF, Ribeiro C, Gama C, Drost K, Chichorro M, Vilallonga F, Hofmann M, Linnemann U (2017) Provenance of upper Triassic sandstone, southwest Iberia (Alentejo and Algarve basins): tracing variability in the sources. International Journal of Earth Sciences 106:43–57

Pereira R, Alves TM, Mata J (2017) Alternating crustal architecture in West Iberia: a review of its significance in the context of NE Atlantic rifting. J Geol Soc Lond Spec Publ 174:522–540

Pinheiro L, Wilson R, Reis RP, Whitmarsh R, Ribeiro A (1996) The western Iberia margin: a geophysical and geological overview. Proc Ocean Drill Program Sci Res 149:3–23

Priem HNA, Boelrijk NAIM, Verschure RH, Hebeda EH (1965) Isotopic ages of two granites on the Iberian continental margin: The Traba Granite (Spain) and the Berlenga Granite (Portugal). Geologie en Mijnbouw 10:353–354

Quesada C (1991) Geological constraints on the Paleozoic tectonic evolution of tectonostratigraphic terranes in the Iberian Massif, Tectonophysics 185, 225–245.

Rasmussen ES, Lomholt S, Andersen C, Vejbæk OV (1998) Aspects of the structural evolution of the Lusitanian Basin in Portugal and the shelf and slope area offshore Portugal. Tectonophysics 300: 199-225.

Ravnås R, Windelstad J, Mellere D, Nøttvedt A., Sjøblom TS, Steel RJ, Wilson RCL (1997) A marine Late Jurassic syn-rift succession in the Lusitanian Basin, western Portugal—tectonic significance of stratigraphic signature. Sedimentary Geology 114:237-266

Ribeiro A, Munhá J, Dias R, Mateus A, Pereira E, Ribeiro L, Fonseca PE, Araújo A, Oliveira JT, Romão J, Chaminé HI, Coke C, Pedro JC (2007) Geodynamic evolution of the SW Europe Variscides. Tectonics 26 (6):TC6009 https://doi.org/10.1029/2006tc002058.

Ribeiro A, Quesada C, Dallmeyer RD (1990) Geodynamic evolution of the Iberian Massif. In: Dallmeyer, R.D., Martínez-García, E. (Eds.), Pre-Mesozoic Geology of Iberia. Springer Verlag, Berlin, Heidelberg, pp. 397–410

Rino S, Komiya T, Windley BF, Katayama I, Motoki A, Hirata T (2004) Major episodic increases of continental crustal growth determined from zircon ages of river sands implications for mantle overturns in the Early Precambrian: Physics of the Earth and Planetary Interiors, v. 146, p. 369–394, doi:10.1016/j.pepi.2003.09.024

Rodrigues B, Chew DM, Jorge RCGS, Fernandes P, Veiga-Pires C, Oliveira JT (2015) Detrital zircon geochronology of the Carboniferous Baixo Alentejo Flysch Group (South Portugal); constraints on the provenance and geodynamic evolution of the South Portuguese Zone. Journal of the Geological Society 172(3):294-308

Schneider S, Fürsich FT, Werner W (2009). Sr-isotope stratigraphy of the Upper Jurassic of central Portugal (Lusitanian Basin) based on oyster shells. International Journal of Earth Sciences 98:1949-1970

Shaw J, Gutiérrez-Alonso G, Johnston ST, Galán DP (2014). Provenance variability along the Early Ordovician north Gondwana margin: Paleogeographic and tectonic implications of U-Pb detrital zircon ages from the Armorican Quartzite of the Iberian Variscan belt. GSA Bulletin 126:702-719

Simancas JF (2019) Variscan Cycle. In: Quesada C., Oliveira J. (eds) The Geology of Iberia: A Geodynamic Approach. Regional Geology Reviews. Springer, Cham. https://doi.org/10.1007/978-3-030-10519-8_1

Simancas JF, Tahiri A, Azor A, Lodeiro FG, Martínez Poyatos DJ, El Hadi H (2005) The tectonic frame of the Variscan-Alleghanian orogen in southern Europe and northern Africa. Tectonophysics 398:181–198

Soares AF, Kullberg JC, Marques JF, Rocha RB, Callapez P (2012) Tectono-sedimentary model for the evolution of the Silves Group (Triassic, Lusitanian basin, Portugal). Bull Soc Géol France 183 (3):203–216

Sousa M, Sant'Ovaia H, Tassinari C, Noronha F. (2014) Geocronologia U-Pb (SHRIMP) e Sm-Nd do ortognaisse biotítico do Complexo Metamórfico da Foz do Douro (NW de Portugal). Comunicações Geológicas 101:225-228

Stanton N, Manatschal G, Autin J, Sauter D, Maia M, Viana A (2016) Geophysica lfingerprints of hyper-extended, exhumed and embryonic oceanic domains: theexample for the Iberia-Newfoundland rifted margins. Mar Geophys Res. 37:185–205

Stapel G, Cloetingh S, Pronk B (1996) Quantitative subsidence analysis of the Mesozoic evolution of the Lusitanian basin (western Iberian margin). Tectonophysics 266:493-507.

Talavera C, Montero P, Martínez Poyatos D, Williams H (2012) Ediacaran to Lower Ordovician age for rocks ascribed to the Schist Graywacke Complex (Iberian Massif, Spain): evidence from detrital zircon SHRIMP U–Pb geochronology. Gondwana Res 22:928–942

Taylor AM, Gowland S, Leary S, Keogh KJ, Martinius AW (2014). Stratigraphical correlation of the Late Jurassic Lourinhã Formation in the Consolação Sub-basin (Lusitanian Basin), Portugal. Geological Journal 49:143-162

Terrinha P. et al. (2019) Rifting of the Southwest and West Iberia Continental Margins. In: Quesada C., Oliveira J. (eds) The Geology of Iberia: A Geodynamic Approach. Regional Geology Reviews. Springer, Cham. https://doi.org/10.1007/978-3-030-11295-0_6

Valverde-Vaquero P, Bento-dos-Santos T, González-Clavijo E, Díez-Montes A, Ribeiro ML, Solá AR, Dias-da-Silva Í (2011) The Berlengas Archipelago granitoids within the frame of the Variscan Orogeny, W Portugal: new data and insights. 7th Hutton Symposium on Granites and Related Rocks, Ávila, 153

Vanney J-R, Mougenot D. (1981) La plate-forme continentale du Portugal et les provinces adjacentes: analyse geomorphologique. Mem. Serv. Geol. Portugal, 28.

Vermeesch P (2012) On the visualisation of detrital age distributions. Chem Geol 312–313:190–194

Vermeesch P (2013) Multi-sample comparison of detrital age distributions. Chem Geol 341:140–146

Wang W, Zhang P, Yu J, Wang Y, Zheng D, Zheng W., ... Pang J. (2016) Constraints on mountain building in the northeastern Tibet: Detrital zircon records from synorogenic deposits in the Yumen Basin. Scientific reports 6(1):1-8

Wilson RCL (1979) A reconnaissance study of Upper Jurassic sediments of the Lusitanian Basin. Ciências da Terra 5:53–84

Wilson RCL (1989) Mesozoic development of the Lusitanian Basin, Portugal. Rev. Soc. Geol. Esp. 1:393-407

Wilson RCL, Hiscott R, Willis M, Gradstein F (1989) The Lusitanian Basin of west central Portugal; Mesozoic and Tertiary tectonic, stratigraphic and subsidence history. In: Tankard, A. & Balkwill, H., Extensional tectonics and stratigraphy of the North Atlantic margins. AAPG Memoir 46:341–361

Wright VP, Wilson RCL (1984) A carbonate submarine-fan sequence from the Jurassic of Portugal. Journal of Sedimentary Research 54(2):394-412

Xiang W, Griffin WL, Jie C., Pinyun H, Xiang LI (2011) U and Th contents and Th/U ratios of zircon in felsic and mafic magmatic rocks: Improved zircon-melt distribution coefficients. Acta Geologica Sinica-English Edition 85(1):164-174

FIGURES CAPTIONS

Fig. 1: Geological framework of the studied deposits. (A) Major tectono-stratigraphic units of the Iberia Massif. CZ: Cantabrian Zone; WALZ: West Asturian-Leonese Zone; GTMZ: Galicia - Trás-os-Montes Zone; CIZ: Central Iberian Zone; OMZ: Ossa Morena Zone; SPZ: South Portuguese Zone. (B) The Lusitanian Basin covering different tectono-stratigraphic units and bounded to the west by the Berlengas Block (BB). (C) Jurassic and basement outliers in central west Iberian margin and location of the sampled sections (black diamonds). PTFZ: Porto-Tomar Fault Zone. Key sites for the Jurassic stratigraphy in the Lusitanian Basin are also indicated. Small grey diamonds indicate the location of other published detrital zircon data for basement (A and B) and Mesozoic (C) units used in this investigation.

Fig. 2: Stratigraphic framework for the beds sampled in the Lusitania Basin. Based on Rasmussen et al (1998), Pena dos Reis et al. (2000), Duarte and Soares (2002), Azerêdo et al. (2003), Schneider et al. (2009), Kullberg and Rocha (2014).

Fig. 3: Stratigraphic sections sampled for U-Pb zircon geochronology. Geographic location in Fig. 1 and stratigraphic setting in Fig. 2.

Fig. 4: Pie diagrams and Kernel density plots of detrital zircon ages for Lower and Upper Jurassic units sourced by the Berlengas Block. Shadow areas in the insets for 750-200 Ma represent characteristic zircon forming events already recognized for Cretaceous deposits from the Iberian Atlantic margin (Dinis et al. 2016).

Fig. 5: Plot of zircon ages and respective Th/U ratios. Note the different Th/U ratios in younger zircons collected in the Toarcian of Peniche (LJ-Ab) and the Kimmeridgian-Tithonian of Praia da Amoreira (UJ-Am).

Fig. 6: MDS map obtained with the detrital zircon age data for the studied deposits and published ages for different terranes that outcrop in West Iberia. The map pulls apart samples with different spectra, using the Kolmogorov Smirnov effect size as a dissimilarity measure (Vermeesch 2013). Basement data for the Central Iberian Zone (CIZ) from Talavera et al. (2012), Pereira et al. (2012a) and Shaw et al (2014); for the Ossa Morena Zone (OMZ) from Linnemann et al. (2008) and Pereira et al. (2012b); for the South Portuguese Zone (SPZ) from Pereira et al. (2012b, 2014) and Rodrigues et al. (2015); for sedimentary successions deposited at the contact OMZ-CIZ in

association with the Porto-Tomar Fault Zone (PTF-SS) from Dinis et al. (2012, 2018). One sample of OMZ is plotted differently from the main cluster for this zone.

Fig. 7: Proposed Variscan basement units in the western edge of the Lusitanian Basin based on detrital zircon results. Arrows indicate detrital zircon signatures for different stratigraphic intervals; main frequency peaks in bold and secondary peaks between brackets. Detrital zircon age results for Triassic strata form Pereira et al. (2016) and Dinis et al (2018), and for Cretaceous strata from Dinis et al (2016). The inset is a schematic profile depicting an overall basement tilt partially responsible for the differences in age signatures between east- and west-derived deposits.

Figure 1

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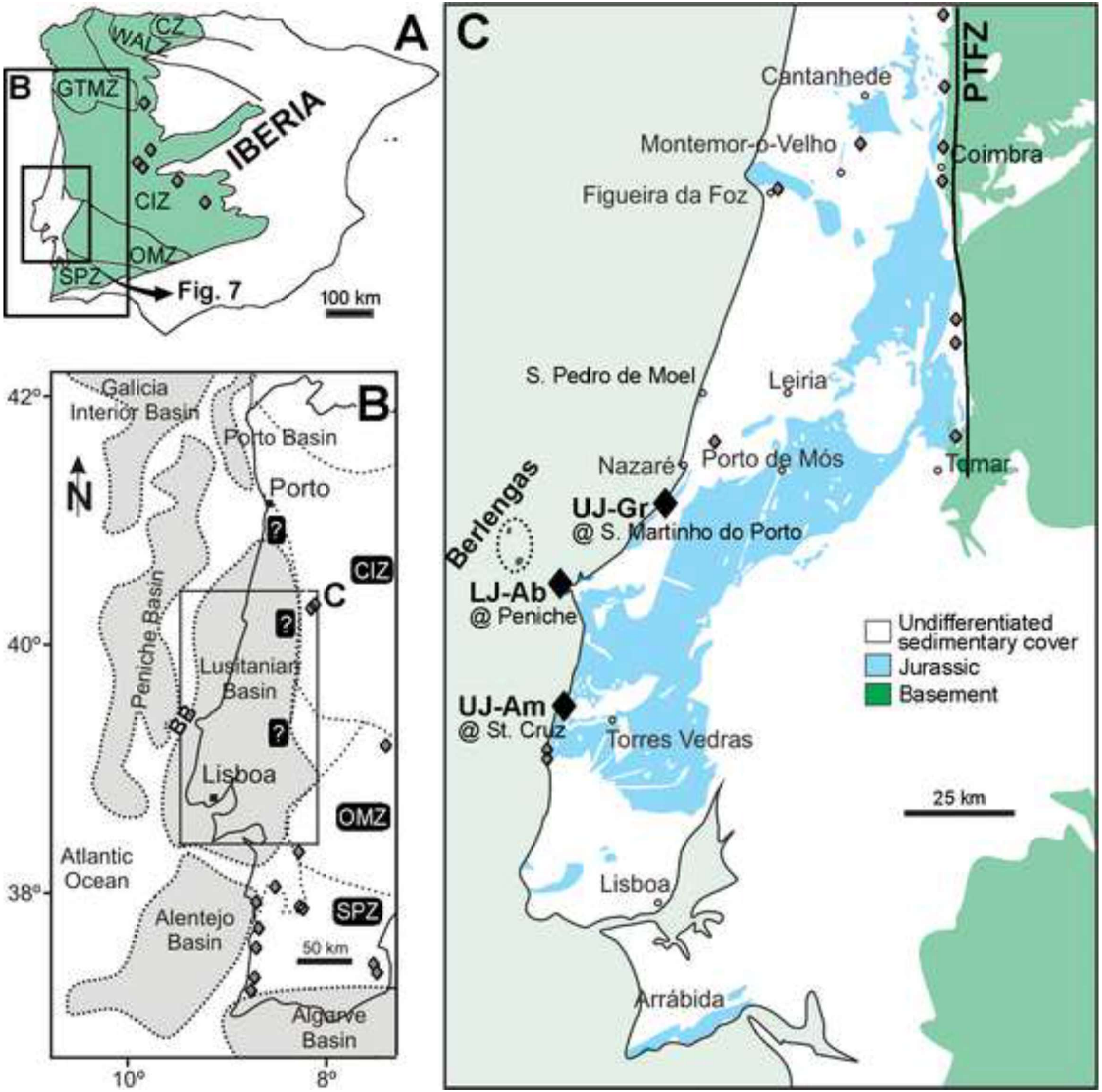

Figure 2

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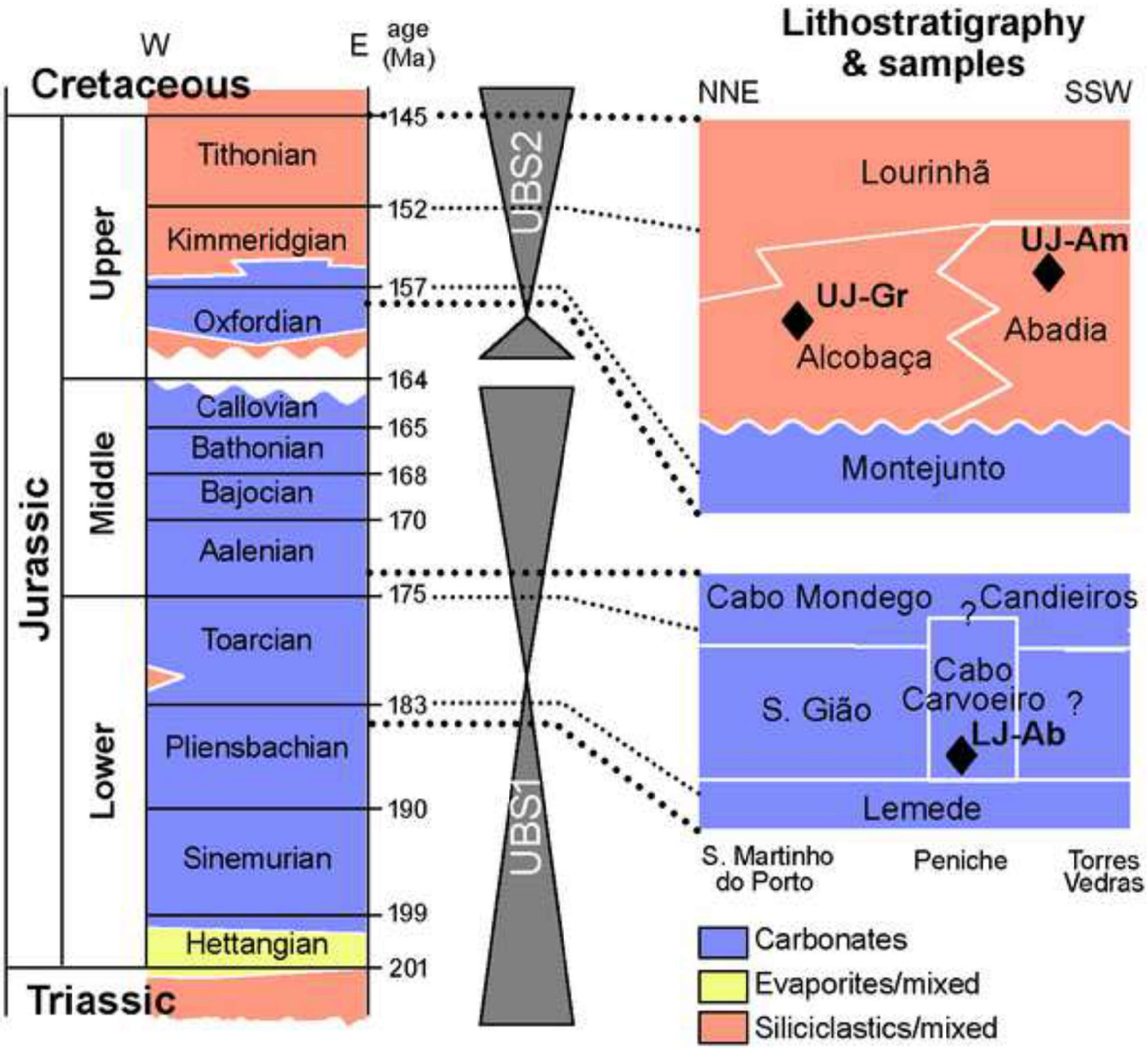

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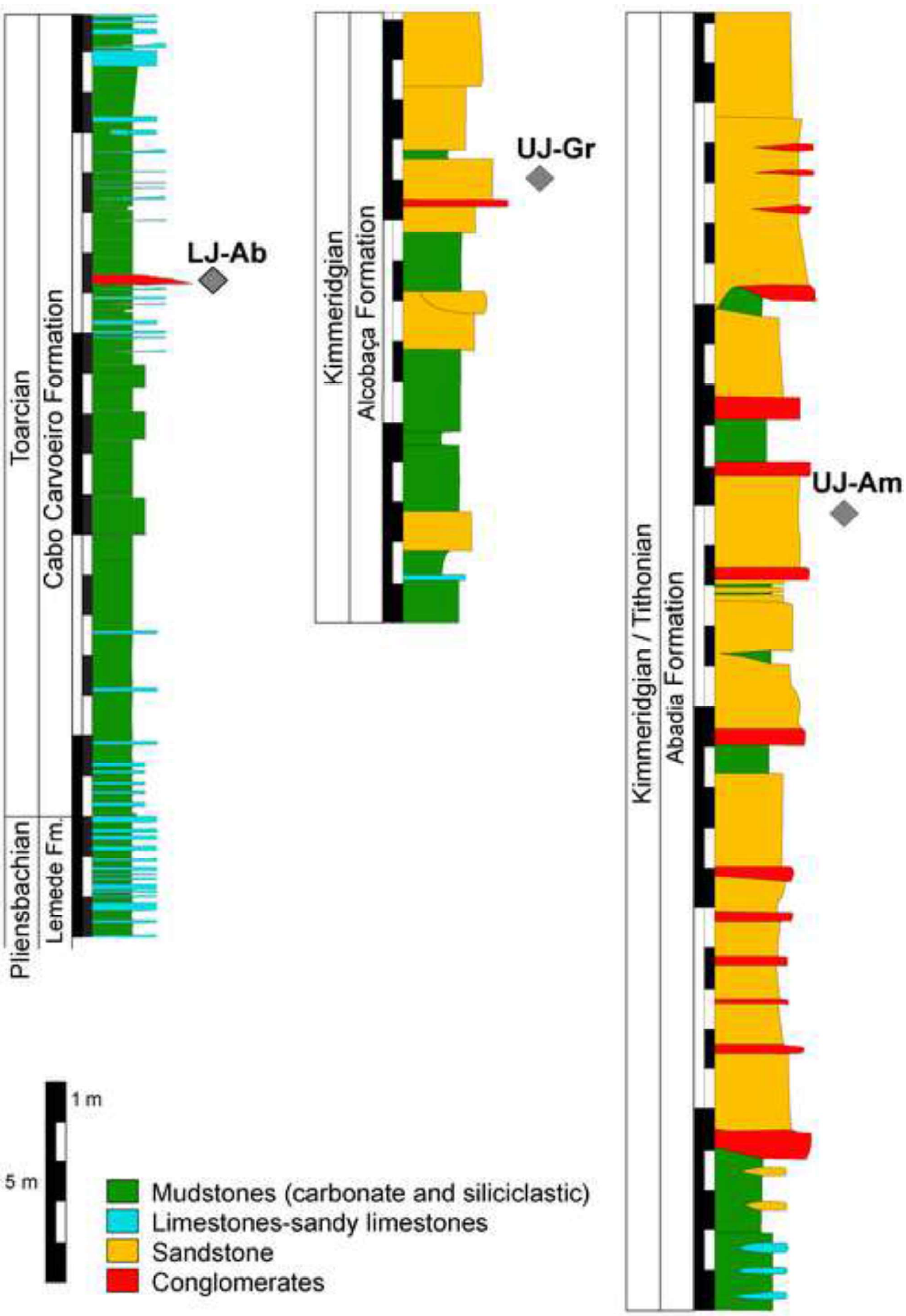

Figure 4 Click here to access/download;Figure;Fig.4.jpg

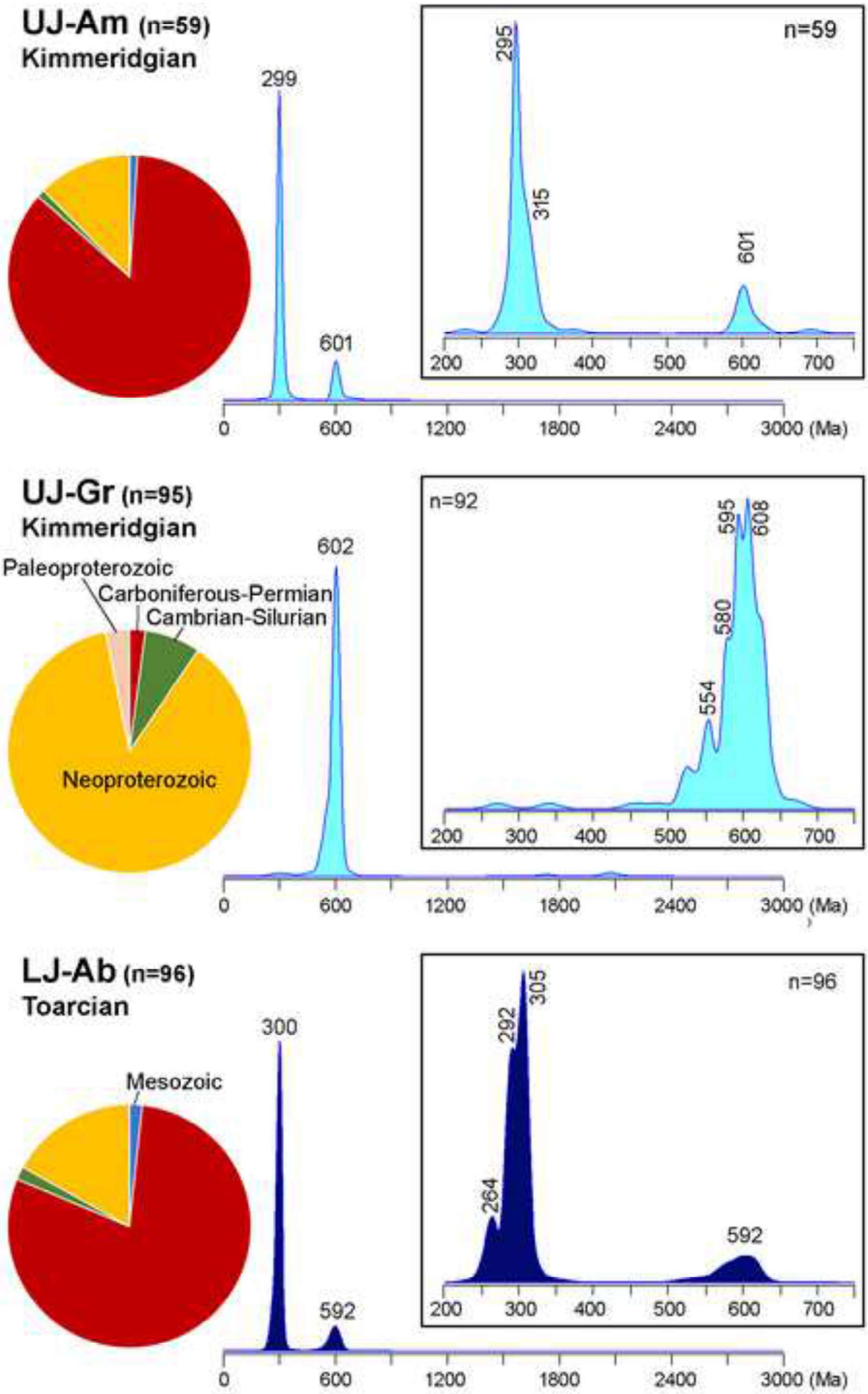

Figure 5

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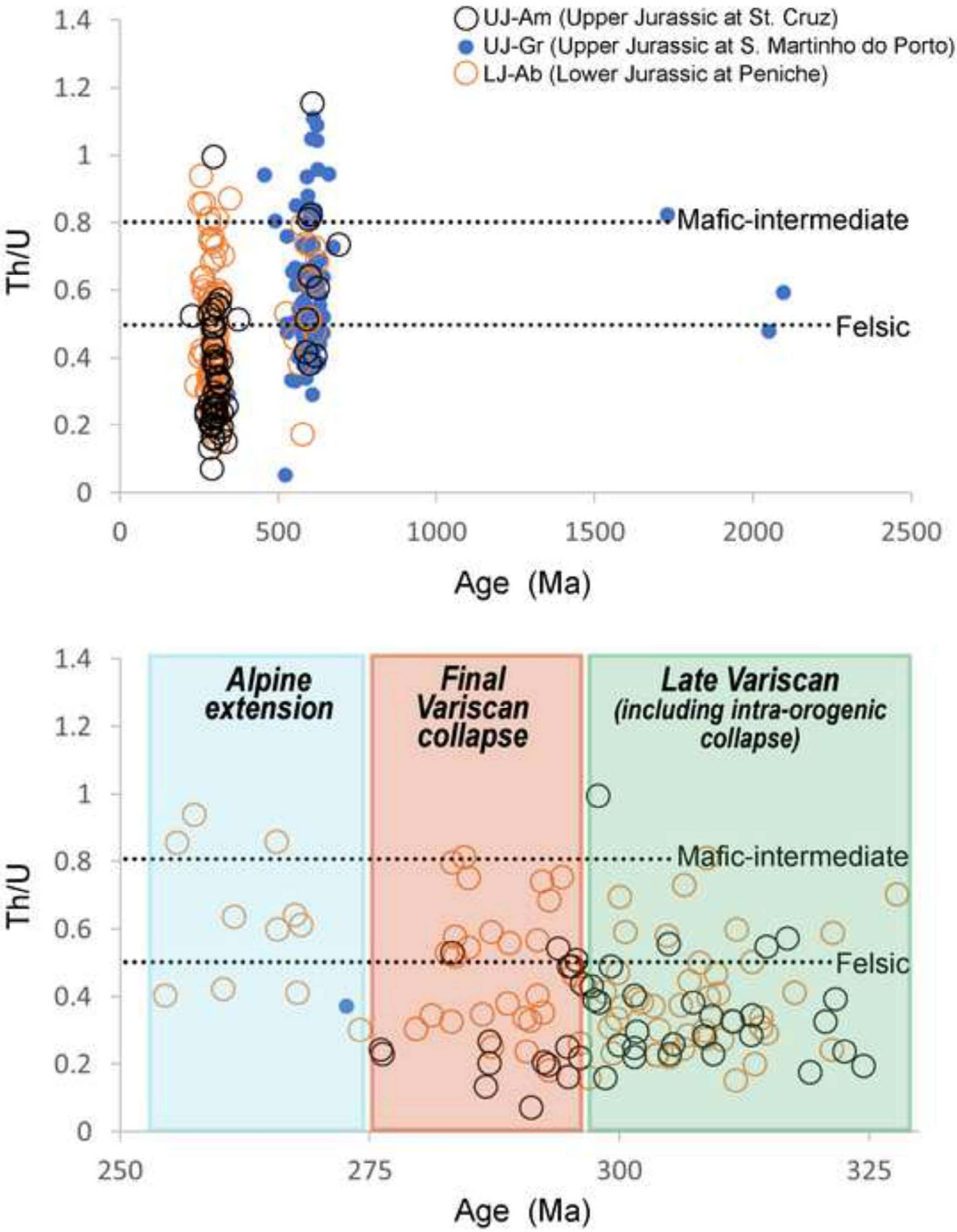

Figure 6

Click here to access/download;Figure;Fig.6.jpg

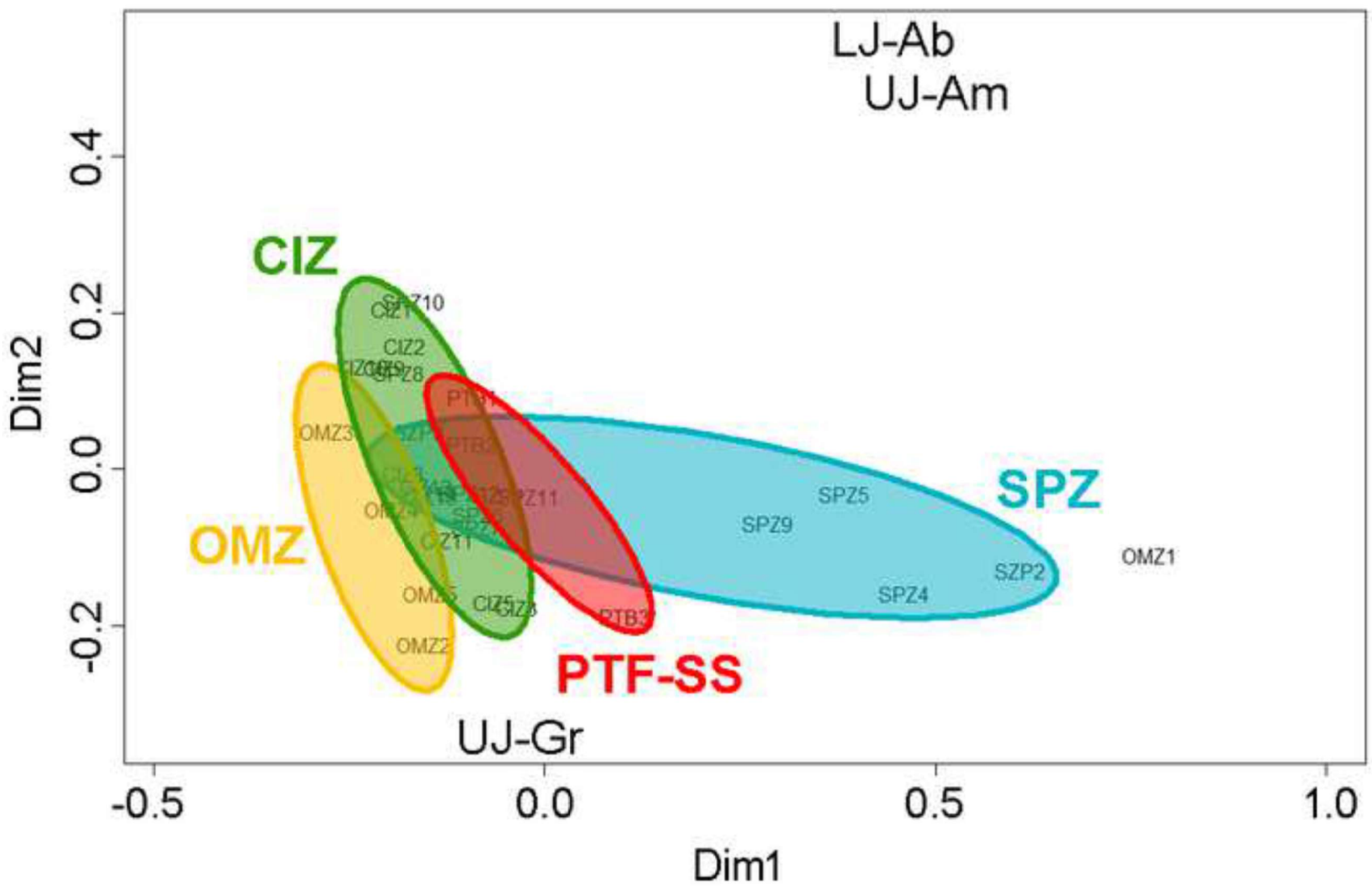

Figure 7

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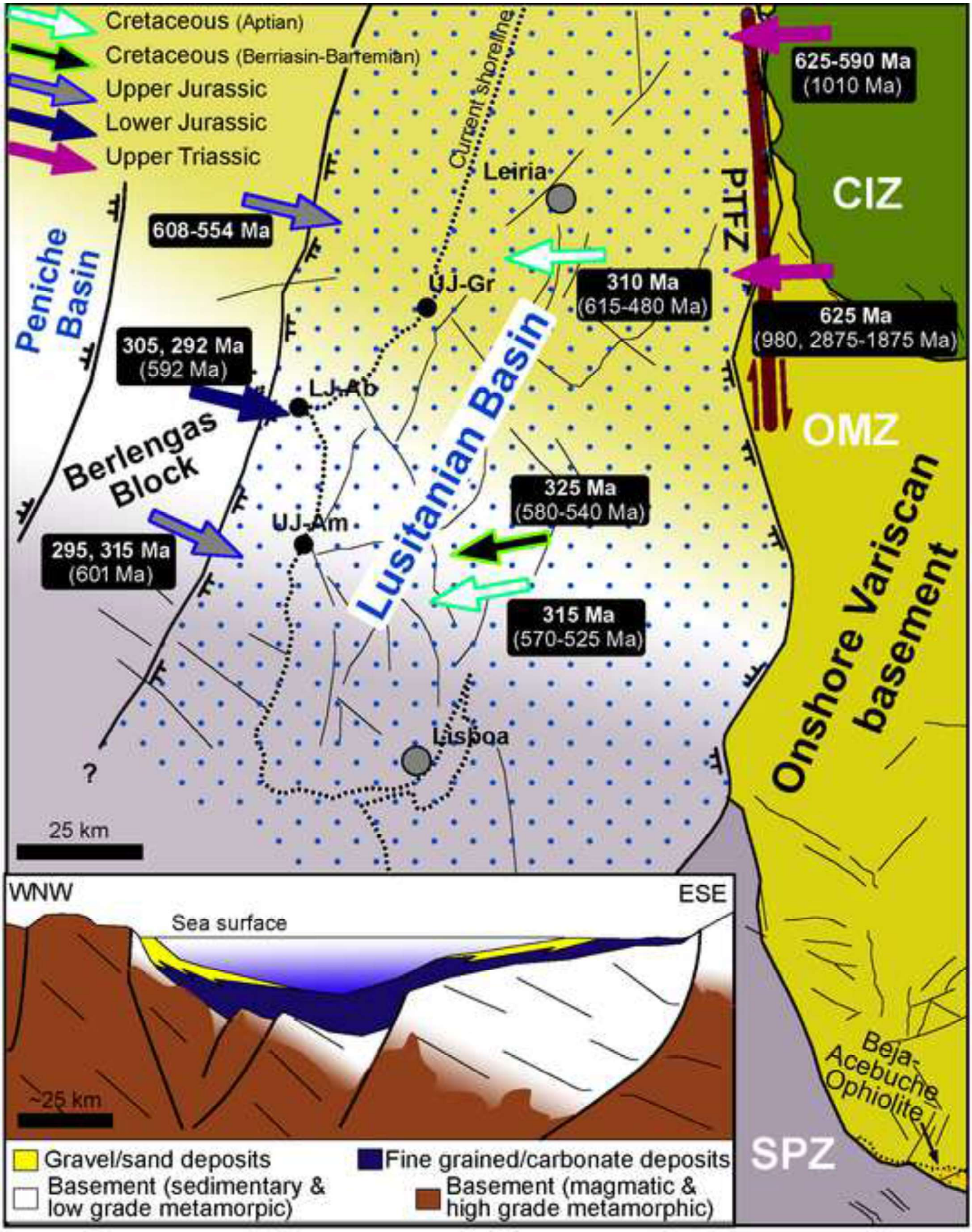

Supplementary Material

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SupplementaryFile_Data.xlsx