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# A tectonic carpet of Variscan flysch at the base of an unrooted accretion prism in NW Iberia: U-Pb zircon age constrains from sediments and volcanic olistoliths

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**Abstract.** The allochthonous complexes of Galicia – Trás-os-Montes Zone (NW Iberia) are part of the tectonic stack that unrooted the Variscan accretionary prism. They are formed by individual tectonic slices marked by specific tectono-metamorphic evolution, which was piled up in a piggy-back thrust complex onto its relative autochthon, the Central Iberian Zone (CIZ). Consequently, allochthony decreases towards lower, more external and younger thrust sheets. The lowermost unit of this pile of slivers is known as Schistose Domain or Parautochthon and bears low metamorphic grade, contrasting with the higher temperatures and pressures estimated for the upper allochthonous units, but sharing the stratigraphic sequence with the underlying autochthon. The Parautochthon is divided in two structural and stratigraphic sub-units: i) the Lower (LPa) made of synorogenic flysch-type sediments with varied turbiditic units and olistostrome bodies, showing Upper Devonian-lower Carboniferous age on base of the youngest zircon populations and fossiliferous content; ii) the Upper (UPa), composed of highly deformed pre-orogenic upper Cambrian-Silurian volcano-sedimentary sequence comparable with both the nearby autochthon and the HP-LT Lower Allochthon, laying structurally above. The UPa thrusted onto the LPa by the the Main-Trás-os-Montes Thrust; and the LPa detached from the CIZ relative autochthon by a regional structure (Basal Lower Parautochthon Detachment) which follows the favourable Silurian carbonaceous beds.

A review on the detrital zircon studies of the synorogenic LPa complemented by 17 new samples geochronology is here presented. The results support the extension of the LPa underneath the NW Iberia allochthonous complexes, from Cabo Ortegal, to Bragança and Morais Massifs. Its current exposure follows the lowermost tectonic boundary between the Galicia – Trás-os-Montes (allochthon) and Central Iberian (autochthon) Zones. Youngest zircon age populations point to a maximum sedimentation age for the LPa formations ranging from Famennian to Serpukhovian and endorse the piggy-back evolution inside this unit, mimicking the general structure of the Galicia – Trás-os-Montes Zone.

The zircon populations in the LPa allow constraining the sedimentary provenance areas, showing the intervention of nearby sources (mostly the UPa) and/or multiply recycled/long transport sediments with typically N-Central Gondwana age fingerprint, also found in the Lower Allochthon, UPa and Autochthon. Complementary geochronology of volcanic olistoliths trapped in the LPa sediments and of upper Cambrian to Upper Ordovician rhyolites from the UPa is also presented, showing a direct relation between the major block's source area (UPa) and the setting place (LPa). Old zircon age patterns show that the LPa sedimentary rocks were recycled from detrital rocks of the allochthon (advancing wedge) and the nearby autochthon (peripheral bulge).

## 1 Introduction

Synorogenic marine basins engage most of the known marine geodynamic settings, from active to passive earthquake-prone margins (e.g. Dickinson and Renzo, 1980; Garzanti et al., 2007; DeCelles, 2012). They are found associated to Archean and to Phanerozoic orogens (e.g. Mulder et al., 2017; Kuski et al., 2020; Wilmsen et al., 2009; Liang and Li, 2005) and they hold key evidences to understand the geographic and geodynamic evolution of modern and ancient orogenic belts.

A common sedimentological feature of all synorogenic marine basins is the cyclicity of earthquake-triggered turbiditic flows that promote a variety of sedimentary facies, from cohesive rhythmic flysch sequences to chaotic large-scale mass-wasting bearing heterometric size blocks or olistoliths (e.g. Coleman and Prior, 1988; Eyles, 1990, Festa et al., 2020), also denominated Block-in-Matrix formations (BIMF) (Festa et al. 2016). Because the most probable source areas of the sediments and olistoliths that fed these basins are in the surrounding orogenically active highs, their stratigraphy can give important clues on the orogen topographic variation in space and time (e.g. Ducassou et al., 2014; Chiocci and Casalbore 2017).

The synorogenic basins that are formed during continental convergence are gradually incorporated in the active margin as tectonic slices in the accretionary complex, especially at the base, forming a tectonic carpet (e.g. Festa et al., 2019; Kuski et al. 2020, and references in). The progradation of the tectonic front and the basin depocenter, allows a systematic intrabasinal sedimentary recycling (i.a. wild flysch) and mixing of the synorogenic sediments with other external sources (e.g. Franke and Engel, 1986; Bütler et al., 2011) producing mixed signals of difficult paleogeographic interpretation, if taken lightly. The key to access this problem rests in the regional study of the basin stratigraphy, including the flysch sequences, the mass-wastings, and the petrography of the olistoliths (Festa et al., 2019, 2020). Complementary, the detailed geological recognition of the basement and surrounding areas of the synorogenic basins is crucial to identify discriminatory aspects that can help to constrain different variables, such as sediment transport distance, regional and local tectonic settings, and paleogeographic limitations (e.g. Alonso et al., 2015; Festa et al. 2016, Krastel et al., 2019).

The sedimentological models can be refined using detrital zircon geochronology. This tool is commonly used to trace source-to-sink relationships, thru different statistical approaches that compare zircon age populations between detrital rocks (e.g. Meinhold et al., 2011, 2013; Linnemann et al., 2012, 2014). One of the most successful and visual statistical procedures is the zircon age clustering using the Multidimentional Scaling (MDS) (Vermeech, 2018), that gives a graphic output of the Kolmogorov-Smirnov test while using a large amount of samples with individual zircon age populations (e.g. Pereira et al., 2020a, Gutiérrez Alonso et al., 2020).

In the southwestern branch of the European Variscan Belt (c.a. 390-300 Ma, Fig. 1) (e.g. Martínez Catalán et al., 2007), the Iberian Massif preserves some of the best examples of Phanerozoic synorogenic marine basins, that reflect different tectonic settings along the belt during the Upper Devonian-late Carboniferous collision of Laurussia and Gondwana to from Pangea (e.g. Oliveira et al., 2019).

In SW Iberia, the Late Devonian – late Carboniferous flysch basins appear on both sides of the oceanic suture that separates Laurussia from Gondwana (Pereira et al., 2012; Pérez-Cacerez et al., 2017; Braid et al., 2011; Silva et al., 1990). In the Gondwana-side, the Late Devonian – early Carboniferous marine sedimentation has Gondwana-type sources with massive contribution of intrabasinal volcanism in the Tournaisian-Visean period (Pereira et al., 2012, 2020a). On the Laurussian side, sediments that filled the synorogenic marine basins resulted from intrabasinal recycling processes and source areas located on both continents. In this case, the sediments were systematically imbricated at the base of the advancing orogenic front, towards inland Laurussia from the Late Devonian (Pulo do Lobo Zone) to the upper Carboniferous (southwestern South Portuguese Zone) (Pereira et al., 2012, 2020a; Pérez-Cacerez et al., 2017; Braid et al., 2011; Jorge et al., 2013).

The study-case of this paper engages the NW Iberia synorogenic marine basins. In this sector, these basins have been classically classified as foreland basins laying on top of N-Gondwana Cambrian to Early Devonian passive margin sequences (Martínez Catalán et al., 2004, 2008, 2016; Dias da Silva et al. 2015). The sedimentary sources of the synorogenic flysch and BIMF deposits are related to the development and unrooting of a Variscan accretionary prism (the Galicia-Trás-os-Montes Zone) onto Gondwana, and to the development of a peripheral bulge in the passive margin of Gondwana (Dias da Silva et al. 2015). The Variscan synorogenic basins have been incorporated into the base of the allochthonous wedge as a parautochthonous unit, and then emplaced onto the autochthonous terrain of NW Iberia (Dias da Silva et al. 2015, González Clavijo et al., 2016). The basin depocenter migrated towards inland Gondwana from the Late Devonian to the late Carboniferous following the progression of the orogenic front, from the Galicia-Trás-os-Montes Zone (GTMZ), to the Central Iberian Zone (CIZ) (Martínez Catalán et al., 2016), following to the Western Asturo-Leonese zone (WALZ) and finally to the Cantabrian Zone (CZ) (Gutierrez Alonso et al., 2020).

In both NW and SW Iberia basins, zircon geochronology has been used to constrain sedimentary provenance based on the fingerprint of sources and basin stratigraphic units (Martínez Catalán et al., 2016; Pereira et al., 2012; Pérez-Cacerez et al., 2017; Braid et al., 2011; Jorge et al., 2013). While in the SW and in the Cantabrian Zone recent works have demonstrated the importance of the MDS statistical approach in identify the relationships between source and sink (Pereira et al., 2020b; Gutierrez Alonso et al., 2020), in NW Iberia this work scheme was not been applied to date.

In this work we present a sound field revision, supported by new structural and zircon geochronology of igneous and detrital zircons, which enables a deep study of the parautochthonous units of the GTMZ defined in this work as Upper Parautochthon (UPa; preorogenic) and Lower Parautochthon (LPa; synorogenic) (e.g. Dias da Silva et al., 2015). Our field revision and new geochronological zircon data allowed the extension of these units to different sectors of the GTMZ, extending the area covered by the UPa and LPa to virtually all the allochthonous complexes of NW Iberia. New field work also recognizes the diverse types of flysch complexes and mélanges present in the LPa, frequently concealed by Variscan polyphasic and pervasive deformation. Tectonic and sedimentary mélanges have been recognized; they combine to produce polygenetic mélanges using the terminology by Festa et al. (2019; 2020). Moreover, the detrital zircon age fingerprinting using MDS (ISOPLOT-R, Vermeech, 2018) performed in this work (described in detail in Supplementary File) offers a new general view of the LPa geotectonic setting at the Variscan times and sets new constrains on the source-areas of the synorogenic sediments and blocks. This allows a better view on the paleogeography and geodynamic setting of the Late Devonian-lower Carboniferous flysch basins in NW Iberia and their relationship with the surrounding (exposed) tectonic units in the shoulders of the Variscan marine basins.

## 2 Geological Setting

In the rootless Variscan accretionary wedge which forms the Variscan Massif of NW Iberia – the so called Galicia Trás-os-Montes Zone – (Figs. 2 and 3) (Ribeiro, 1974, Schermmeron and Kotsch, 1984, Martínez Catalán et al. 2009; Ballèvre et al., 2014; Martínez Catalán et al. 2014; Azor et al., 2019) a significant structural unit has been identified as a remnant of former oceans/seas (Lower Ordovician Rheic ocean and an Early Devonian suprasubduction ophiolite) that marks the suture zone of the Laurrussia-Gondwana continental collision that led to the formation of Pangea; this unit is known as Middle Allochthon or Ophiolitic Unit (Gómez Barreiro et al., 2007; Martínez Catalán et al., 2009; Stampfli et al., 2013; Ballèvre et al., 2014; Arenas and Sánchez-Martínez, 2015; Azor et al., 2019) and currently separates the Upper Allochthon (Upper units) and the Lower Allochthon (Basal units). The Upper Allochthon (UA) is considered a far-travelled ribbon-like terrane that drifted away in the Lower Ordovician from the Gondwanan margin during the opening of the Rheic Ocean, and accreted to Laurussia in the Silurian (Gómez-Barreiro et al. 2007). It includes 2 tectonically stacked units, each presenting early-Variscan (390-380 Ma) HP-HT and IP-MT metamorphism (e.g. Martínez Catalán et al., 2019). The Lower Allochthon (LA) is made of a set of nappe folds and tectonic slices (Farias et al., 1987; Piçarra et al., 2006; Díez Fernández et al., 2010; Dias da Silva et al., 2014; Dias da Silva et al., 2015) considered to have been cut off from the most seaward rim of Gondwana (Murphy et al., 2008) during the continental subduction (HP-LT metamorphism) and obduction (retrogression to amphibolite and greenschist facies) recording the initial stages of Variscan continental collision at approximately 370-360 Ma (Munhá et al., 1984; Arenas et al., 1995, 1997; Gil Ibarguchi and Dallmeyer, 1991; Gil Ibarguchi, 1995; Rubio Pascual et al., 2002; Rodríguez et al., 2003; López-Carmona et al., 2010, 2014).

A tectonic unit, displaying low metamorphic grade, separates the above-mentioned allochthons from their relative autochthon, the Central Iberian Zone (CIZ). This unit, named Schistose Domain (Farias et al., 1987) or Parautochthon (Pa) (Ribeiro et al., 1990; Martínez Catalán et al., 1997) was considered for many years as a thick anomalous Silurian sequence, contrasting with the condensed graphite-rich sequences described in the underlying autochthon (CIZ). The paleogeographic affinity of both domains was highlighted by identical N-Gondwana Silurian graptolite and conodont faunas (Sarmiento et al. 1998; Piçarra et al., 2003; 2006a; 2006b). However, the stratigraphic and deformative aspects of the lower tectonic sheets of Pa in the transition to the CIZ, pointed to that section was part of a synorogenic basin with possible (Middle-Late) Devonian age (Antona and

Martínez Catalán, 1990; González Clavijo and Martínez Catalán, 2002; Martínez Catalán et al., 2004; Pereira et al., 2009; Rodrigues et al., 2013).

This led to a later division in two tectonically overriding units, Upper and Lower Parautochthon (UPa and LPa), in the meaning firstly proposed by Rodrigues et al. (2006a; 2006b) and updated by Dias da Silva et al. (2014; 2015; 2016). This division restricts the UPa to a pre-Variscan upper Cambrian-Silurian sequence comparable with the CIZ and LA that was affected by Variscan recumbent folds and thrusts; and defines the LPa as an imbricated thrust sequence bearing slices of a foreland synorogenic basin, with the younger slices in the transition to the CIZ (e.g. Martínez Catalán et al., 2016). This proposal required a relocation of the bounding thrust structures of the lower tectonic sheets of the GTMZ:

i) the LA-UPa thrust (basal thrust of the Centro-Transmontano thrust complex in the meaning of Ribeiro et al. 1990b) into an upper structural position;

ii) the UPa-LPa thrust system named as Main Trás-os-Montes Thrust (MTMT) (Ribeiro, 1974; Ribeiro and Ribeiro, 2004; Meireles et al., 2006; Pereira et al. 2006) to a lower structural position (Dias da Silva et al., 2014). The MTMT is an up to 1000 m thick gently dipping shear-zone responsible by the thrusting of the upper Cambrian-Silurian (pre-orogenic UPa) sequence onto the syn-orogenic LPa, allowing the thickening the upper crust during the Tournaisian-Visean stage (Dias da Silva et al., 2014; 2015; 2016; 2020; Azor et al., 2019);

iii) At the base of the LPa another major fault structure named the Basal Lower Parautochthon Detachment (BLPD), also gently dipping, separates the syn-orogenic piggy-back imbricated slices from the structurally underlying autochthon (Dias da Silva et al., 2014). The BLPD was developed following a favorable stratigraphic unit, the condensed Silurian autochthonous sequence formed by carbonaceous cherts and graphitic slates (González Clavijo and Martínez Catalán, 2002; Dias da Silva et al., 2014).

As the northern CIZ autochthonous domain presents an Ediacaran to Lower Devonian sequence (e.g. Sousa, 1984; Valladares et al., 2000; Gutierrez Marco et al., 2019; Sánchez García et al., 2019), the BLPD separates the LPa without substantial upper crustal thickening, which mainly occurs due to the piggy-back thrust-duplexes developed in the syn-orogenic tectonic units (Fig. 2 and sections 4 and 5 in Fig. 3).

In the studied area, the three structural units considered in this work (UPa, LPa and CIZ) underwent a regional Barrovian metamorphism ($M_1$) through the early Variscan compressive events ($C_1$+$C_2$ on the Alcock et al., 2015 proposal) which were later followed by a complex extensional ($E_1$-$M_2$) and compressive ($C_3$-$M_3$) tectonothermal history (Azor et al., 2019; Dias da Silva et al., 2020). Some specialized studies were performed to discriminate if the metamorphic grade at the syn-orogenic units was lower than in the pre-orogenic units by illite crystallinity (Antona and Martínez Catalán, 1990) and Colour Alteration Index in conodonts (Sarmiento and García-López, 1996; Sarmiento et al., 1997) but no conclusive results were attained. This matches with the Matte (1968) conclusions for the autochthonous San Clodio syn-orogenic deposits, supporting the same metamorphism and deformation in the Carboniferous than in the underlying autochthonous Ordovician sequence.

## 3 Review of the syn-orogenic marine sequences in NW Iberia

The internal zones of the orogenic belts are considered areas with scarcely preserved related syn-orogenic sequences because of the following denudation caused for the orogeny itself (Martínez Catalán et al., 2008). Nevertheless, Franke and Engel (1986) stated the existence of tectonic slices carrying syn-orogenic sedimentary units from the more internal areas in several European Variscan massifs. In NW Iberia, a deeply eroded part of the chain, the firstly identified syn-orogenic sequence was the San Clodio Series, which is preserved at the core of the late Variscan Sil Syncline, in northern Iberia (Fig. 2 and cross section 2 in Fig. 3). This series is formed by a rhythmic sequence of pelite and greywacke displaying turbiditic features (Riemer, 1966; Pérez-Estaún, 1974) and plant debris pointing to an age Upper Devonian or earlier according to the late author. Detrital zircon studies (samples SO-1 and SO-2 situation in Fig. 4) have reinforced the syn-orogenic character and supported an Upper Mississippian age (Martínez Catalán et al., 2004). Towards the base it displays exotic and lithified blocks and pebbles of carbonaceous chert, quartzite, slate, gneiss and granite (Riemer, 1966). The San Clodio Series is separated from the underlying Ordovician formations by a few metres thick Silurian unit made of black slates, ampelites and lydites, which was sheared and mylonitized forming a basal detachment structure (Barrera Morate et al. 1989). Following the Festa et al. (2019; 2020) terminology, the complete structural unit could be named as a coherent primary succession on top of a sedimentary block-in-matrix (olistostrome) lower part. The lowermost thrust fault band developed on the favourable Silurian rocks may be considered a tectonic mélange in the meaning proposed for those authors.

To the E of the Bragança Complex, the core of the Late Variscan Alcañices Synform (Fig. 2 and cross sections 4 and 5 in Fig. 3) is formed by several LPa syn-orogenic units displaying an intricate structural arrangement made of a number of stacked duplexes folded by a train of NW-SE-trend upright Late Variscan folds ($D_3$ or $C_3$-$M_3$ folds) (González Clavijo and Martínez Catalán, 2002; González Clavijo et al., 2012). The whole pile of tectonic slices has been divided in four major units according the syn-orogenic sequence characteristics; but all of them sharing at the base of every tectonic horse the same condensed black Silurian sequence intensely sheared (González Clavijo and Martínez Catalán, 2002; González Clavijo, 2006). From the top (more internal) structural position to the bottom (more external) the syn-orogenic units are named: Gimonde, Rábano, San Vitero, and Almendra; being each unit younger according detrital zircon research (upper Devonian to uppermost Mississippian), thus supporting a piggy-back stacked tectonic pile (González Clavijo et al., 2012; Martínez Catalán et al., 2016). The highest Gimonde Fm. (Pereira et al., 1999, Meireles et al., 1999a; 1999b) is formed by fine beds of phyllite and metagreywacke, and minor levels of microconglomerates containing exotic and lithified grains and clasts. Its age has been considered Upper Devonian on base of plant debris (Teixeira and Pais, 1973) and palynomorphs (Pereira et al., 1999) which is consistent to the detrital zircon results (samples SO-6, SO-7, SO-8; situation in Fig. 4) (Martínez Catalán et al., 2016). Rábano Fm. (González Clavijo and Martínez Catalán, 2002), structurally underlying Gimonde, comprises diverse lithologies being the most general a block-in-matrix sequence displaying profuse major exotic and lithified olistoliths of rhyolite, acidic volcanic tuffs, epiclastic volcanic rocks, white and gray quartzite, black lydite and ampelite, greywacke, phyllite, and limestone (Fig. 5A). The ages of these big blocks (sometimes hundreds of metres in length) based on radiometric ages and fossiliferous content ranges from Furongian to Emsian (González Clavijo et al., 2012; 2016). At the upper Rábano Fm. a flyschoid sequence made of phyllite, quartzlitharenite, and local microconglomerate holds exotic, lithified and deformed grains and clasts (Fig. 6A, B, and C); including plagioclase and volcanic quartz and explosive quartz shards supporting a vulcanite rich source area for this unit (González Clavijo, 2006). Detrital zircon ages studies performed in this wild-flysch (sample SO-9; situation in Fig. 4) support a syn-orogenic nature and points to an age Tournaisian or younger (González Clavijo et al., 2012; 2016; Martínez Catalán et al., 2016). The Rábano Fm. lies on a sheared condensed black Silurian unit which develops a tectonic mélange and, sometimes, a polygenetic mélange where deformation is superimposed to a sedimentary mélange. The discontinuity of the Silurian unit along the tectonic limit suggests that a strong stretching event was concentrated in this band. Next unit is formed by the San Vitero flysch (Martínez García, 1972) made of phyllite and quartzlitharenite rhythms up to metre thick and local lenses of microconglomerate with exotic, lithified and deformed grains and pebbles (Fig. 6D and E) (González Clavijo and Martínez Catalán, 2002). The base of San Vitero Fm. lays on the lower polygenetic mélange of every tectonic horse made of the black Silurian condensed succession and a block-in-matrix unit (Fig. 7A and 7B). This unit was considered Upper Devonian or younger based on the plant debris (Teixiera et al., 1973) but detrital zircon studies (samples SO-4, SO-5 and SO-13; situation in Fig. 4) support a Tournaisian age or younger (Martínez Catalán et al., 2016).

The tectonically lower multiplex includes the Almendra Fm. (Vacas and Martínez Catalán, 1987) which is a calciturbidite made of phyllite and calcarenite rhythms up to several metres thick (González Clavijo, 2006). Local lenses of conglomerates and microconglomerates holding exotic, lithified and deformed pebbles (Fig. 6F, G and H) of diverse lithologies (phyllite, sandstone, litharenite, quartzite, limestone, ortogneiss, rhyolite, acidic volcanic tuff) were firstly described by Aldaya et al. (1976). Major blocks of black lydite with Silurian graptolites and limestone (Fig. 5B and C) containing abundant fossils (bioclasts of corals, sciphocrinoides, bivalves, gastropods, and tentaculites) have been identified (González Clavijo and Martínez Catalán, 2002; González Clavijo et al., 2016 and there in) and the conodonts seized in the calcarenite yielded Lower Devonian age (Sarmiento et al., 1997). Detrital zircon studies in Almendra Fm yielded Mississippian ages (sample SO-14; situation in Fig. 4), thus supporting the Variscan syn-orogenic origin of this unit (Martínez Catalán et al., 2016). As in the other duplexes, the Almendra coherent unit is underlayered by a sheared band made of a block-in-matrix sequence and the condensed Silurian succession, thus forming a polygenetic mélange (Festa et al., 2019; 2020) (Fig. 4B).

The LPa placed at the eastern rim of the Morais Complex (Fig. 2 and cross section 6 in Fig. 3) was described by Dias da Silva (2014) as a flyschoid syn-orogenic sequence comprising two stratigraphic units (Travanca and Vila Chã Fms.) consisting on coherent primary units, broken beds units and lenses of block-in-matrix units displaying hectometre size olistoliths. The referred clasts are native: intraclasts and soft clasts; and exotic: lithified black lydite and ampelite, and quartzite. At the base, a black Silurian and strongly deformed unit may be considered a tectonic mélange limited by an upper and a lower thrust fault. There are not fossiliferous ages of these units, and the palynomorph study performed by Dias da Silva (2014) was unfruitful because the pollen conservation was hampered by the Variscan thermal conditions. Detrital zircon studies (samples VC-21ZIR; VC-45ZIR; and VC-57ZIR; situation in Fig. 3) support a late Devonian to early Carboniferous age (Dias da Silva et al., 2015).

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In the Marão range, W of Vila Real (Fig. 2), some tectonic slices appertaining to the GTMZ Parautochthon comprise several flyschoid stratigraphic sequences displaying rhythms of phylite and greywacke with some volcanic tuffs towards the top (Pereira, 1987). They are concordantly above the sheared black Silurian unit mostly made of ampelite and lydite, but also having some quartzite and black limestone discontinuous bodies in the upper levels. As this last unit was dated by graptolites as Silurian (Piçarra et al., 2006), it was proposed, without fossiliferous evidences, a Devonian age for the overlying flyschoid units (Pereira et al., 2006). González Clavijo (2006) supported a correlation between these units and the San Vitero flysch, in the Alcañices synform, on base to the lithologies and the stratigraphic position, thus meaning a possible Tournaisian age (Martínez Catalán et al., 2016). In this work we consider the flyshoid sequences as coherent primary units, and the Silurian condensed sequence as a tectonic mélange placed at the base of every tectonic slice. According our proposal of tectono-stratigraphic scheme, all the stacked pile must be considered as belonging to the LPa.

## 4 Extending the Lower Parautochthon

The known existence of the above mentioned syn-orogenic LPa units, partially encircling the GTMZ to the E, fostered a complementary research aimed to recognize the extension of the Variscan syn-orogenic tectonic unit in the GTMZ of NW Iberia (Fig. 2). In this work 17 new radiometric zircon ages were attained in other areas surrounding the Bragança, Morais, and Cabo Ortegal allochthonous complexes.

The detailed description of the zircon geochronology study is presented in Supplementary File and in Supplementary Images 1 to 9. The complete dataset with the new U-Pb isotopic analyses are given in Supplementary Tables 1-17. The reference and complementary U-Pb zircon age datasets used in the MDS process and other statistical procedures are in Supplementary Tables 18 and 19.

### 4.1 Stratigraphic sequences and youngest zircon ages

The Meirinhos area, at the S of the Morais Complex (Fig. 2 and cross section 4 in Fig. 3), was divided in two stratigraphic units: Meirinhos and Casal do Rato following Pereira et al. (2009) and Rodrigues et al. (2003). They were considered syn-orogenic flyschoid deposits bearing olistoliths of quartzite, phyllite, greywacke, acidic volcanite and tuffs, basic vulcanite, limestone, ampelite and lydite by Pereira et al. (2009); however, a latter work proposed a different age, stratigraphic features and structure (Sá et al., 2014) based on the reappraisal of the Lower Ordovician trilobite cruziana ichnofossils previously described by Ribeiro (1974). The fieldwork carried out in our research confirms the earlier proposal and new syn-orogenic features has been identified as slump folds, broken beds, and olistostromes including big olistoliths (Fig. 5D and E). In both stratigraphic units, native and exotic lithified blocks, cobbles and pebbles of the previously stated materials have been identified. The coherent primary unit and the block-in-matrix unit lye on the sheared black condensed Silurian unit, which is bounded, on top and below, by thrust fault structures. This last unit constitutes a tectonic mélange or a polygenetic mélange in some reaches. Fossiliferous ages range from Lower Ordovician trilobite tracks (Ribeiro, 1974; Sá et al., 2014) to Silurian graptolites (Pereira et al., 2009), are here interpreted as the age of olistoliths. Two samples (CR-ZR-01, and MEI-ZR-01, situation in Fig. 4, coordinates in Table 1 and geochronology in Supplementary File) were collected in this area with a youngest attained detrital zircons with Upper Ordovician age (YZ: 439 Ma for both samples) and maximum depositional ages ranging from 466 Ma (CR-ZR-01) and 488 Ma (MEI-ZR-01) (Supplementary File; SI-1), not supporting a syn-orogenic character and definitely not supporting a Lower Ordovician age for these siliciclastic rocks. However, the sedimentary features and the cartographic continuity with the previously described LPa unit east of the Morais Complex (i.a. Travanca Fm. *in* Dias da Silva et al., 2015) make possible to propose a Mississippian age for these syn-orogenic siliciclastic rocks samples.

W of Mirandela, around the village of Sucções, there is a tectonic window modified by late- or post-Variscan NNE-SSW subvertical faults (Fig. 2 and cross sections 3 and 6 in Fig. 3) which displays a flyschoid sequence considered Devonian by Ribeiro (1974) and Silurian with upper small patches of Lower Devonian by Rodrigues et al. (2010). These late authors mapped in this area the MTMT, which places tectonically the UPa to the LPa. The here considered LPa syn-orogenic sequence has flyschoid features and it is made of centimetre to metre rhythms of pelite and greywacke (Fig. 5F) overlying a black ampelite and lydite Silurian sequence with a superimposed strong shearing (Rodrigues, 2008). The proposed Silurian-Devonian age was based on graptolites found in the black lydites (Piçarra et al, 2006) but the younger Variscan detrital zircons (Famennian) found in the flysch during this research in the Upper Schists Fm. (MIR-41, AD-PO-49 and AD-PO-55) and in the Culminating slates and greywackes Fm. (AD-PO-57) (situation in Fig. 4, coordinates in Table 1 and geochronology in Supplementary File) suggest that the black chert bodies are Silurian olistoliths, and/or the graptolite samples were picked up exclusively in the underlying Silurian black unit. The attained zircon ages (SI-4, SI-5) and the flyschoid features enable us to consider this area as a coherent primary unit with olistoliths overlying a tectonic mélange developed in the Silurian carbonaceous rocks.

To the W, in the Vila Pouca de Aguiar region (Fig. 2), the LPa comprised several units limited by thrust planes and bearing stratigraphic successions with changing names during the last years (Rodrigues, 2008) but sharing flyschoid characteristics (Ribeiro, 1974; Ribeiro et al., 1993; Noronha et al., 1998; Ribeiro, 1998; Rodrigues, 2008). The generalized description for all the successions is a rhythmic sequence (millimetre to metre thick) of pelite and greywacke (quartzwacke towards the base) very rich in plagioclase, thus suggesting a great volcanic input in the basin (Rodrigues, 2008). This group of units includes lens-shaped bodies of different sizes made of: grey quartzite, black limestone, acidic metavolcanic rocks, and black lydite and ampelite, being the last two intensely sheared in most of the occurrences (Rodrigues, 2008). After the field exploration we envisage this group of formations as coherent primary units with block-in-matrix parts, which slid along the underlying sheared Silurian black sequence (tectonic mélange) to form duplexes. The age has been considered Silurian-Devonian based on lithological correlation with nearby formations (Ribeiro, 1974; Noronha et al., 1998; Ribeiro, 1998; Pereira, 2000) and Silurian graptolites found by Piçarra et al. (2006). One sample (AD-PO-48B, situation in Fig. 4, coordinates in Table 1 and geochronology in Supplementary File) grabbed in an arkose with lithoclasts yielded a Famennian–Tournaisian age (YZ: 355 Ma; MDA: 364 Ma)(SI-3B) supporting it belongs to the LPa syn-orogenic unit.

At N edge of the Bragança Complex (Fig. 2 and cross section 3 in Fig. 3) the Upper Allochthon HP-HT rocks are in tectonic vicinity with the syn-orogenic unit because of a late Variscan extensional shear zone identified in our field surveys. In this section, at the upper part of the LPa, the presence of exotic and lithified pebbles and greywacke grains was recorded by Ribeiro and Ribeiro (1974). These authors describe (i) epizonal fragments: phyllite, quartz-phyllite, quartzite, acidic volcanic tuffs, black ampelite and lydite; and (ii) meso-catazonal fragments: paragneiss (albite, chlorite and K feldspar), blastomylonites, and biotite-garnet gneisses. In this work metre blocks of those materials have been found in a wider area (Fig. 5G, H and 3A), where some rhyolite, acidic volcanic tuff, black lydite and limestone hectometre-long olistoliths were also identified. The base of the LPa in this section displays the same black Silurian condensed sequence previously described in other areas, and it is also deformed for a complex shear band which in some places also involves block-in-matrix sedimentary bodies, thus creating a polygenetic mélange. The existence of a tectonic duplex consisting in slices repeating the general architecture above described (sheared black lydite and ampelite overlaid by syn-orogenic materials), lately folded by the Late Variscan events, thickened the LPa in this area (Fig. 8). Our detrital zircon research (samples GIM-ZR-01, EC-PO-293 and AD-PO-66, situation in Fig. 4, coordinates in Table 1 and geochronology in Supplementary File) displays a population of detrital zircons of Variscan age (YZ: 327 Ma for GIM-ZR-01, 426 Ma for EC-PO-293 and 431 Ma for AD-PO-66; MDA: 355 Ma, 435 Ma and 496Ma, respectively) confirming the syn-orogenic age of this unit (SI-2A and SI-3A).

The Picon Beach exposure at Cabo Ortegal Allochthonous Complex is placed E of the Ortigueira locality, in the Galicia northern coastline (Fig. 2, and cross section 1 in Fig. 3). There, above the sheared black Silurian sequence placed on the top of the BLPD, a tectonic slice formed by low metamorphic grade fine grey sandstones, flyschoid sequences, and discontinuous block-in-matrix bodies led us to consider it a Variscan syn-orogenic deposit. Our detrital zircon study (PICON-2; situation in Fig. 3, coordinates in Table 1 and geochronology in Supplementary File) yielded a clear Tournaisian or younger age (YZ: 350 Ma; MDA: 357 Ma) (SI-6) thus supporting that the LPa extends as far as the northern Spain coast.

## 5 Lower Parautochthon magmatic olistoliths, their ages and possible source-areas

In several lithostratigraphic units of the LPa exotic and lithified grains, clasts, minor blocks and olistoliths have been identified, some of them previously deformed and metamorphosed (Ribeiro and Ribeiro, 1974; Aldaya et al., 1976; González Clavijo and Martínez Catalán, 2002; Martínez Catalán et., 2016). These fragments presence was considered a proof of its syn-orogenic character, and also evidence that the basin was fed from areas of the Variscan belt already deformed and metamorphosed (Antona and Martínez Catalán, 1990; González Clavijo and Martínez Catalán, 2002; Martínez Catalán et al, 2004; 2008). Complementarily, as above mentioned for the different areas, the fauna and flora findings in those materials display ages from Lower Ordovician to Middle Devonian; this dispersion suggesting the samples were taken in olistoliths as the encompassing material is clearly syn-orogenic on base to the stratigraphic features and the detrital zircon ages (González Clavijo et al., 2016). Trying to confirm this hypothesis, a U-Pb zircon geochronology study on volcanite bodies inside the LPa was performed in four olistoliths (Fig. 4) and completed with previous data from references. (Farias et al., 2014; González Clavijo et al., 2016). The complete description of the samples and the geochronology study is presented in the Supplementary File. Situation of each sample is in Fig. 4 and coordinates are in Table 1.

### 5.1 Magmatic olistoliths ages results

As a complementary study of the detrital zircon in flyschoid sequences, four magmatic rock olistoliths were studied in our research, all of them located in the Alcañices synform and northern Bragança complex areas.

Sample EC-PO-337 was grabbed NE of the Bragança town in an olistolith made of green foliated dacite pyroclastic tuff inside the Rábano Fm. The vulcanite displays clear volcanic quartz crystals and abundant plagioclase fragments. The youngest zircon age is 435 Ma (Telychian) and the magmatic age is 442 Ma (SI-8A) with important age populations defining inherited clusters at 471 Ma, 484 Ma and 494 Ma (Floian to Furongian).

Sample EC-PO-419 was collected in the northern limb of the Verín-Alcañices Synform, to NW of the Bragança Complex in a pervasively foliated medium-grained quartz-eyed acid tuff exposure. Our field revision disclosed the sample was grabbed in one of the olistoliths forming a cluster of diverse lithologies: acid volcanic tuffs, rhyolite, quartzite, lydite, quartzlitharenite and limestone slid into a detrital syn-orogenic sequence. The youngest zircon age has 439 Ma and the magmatic age (youngest population) of this sample is 442 Ma. Other important age populations have presented Floian (474 Ma) and Darriwilian (465 Ma) ages (Supplementary File; SI-8B).

Sample PET-01 was grabbed at the Spanish-Portuguese border in the N side of the Rábano Fm, in an olistolith belonging to a huge cluster extending from N of the Bragança Allochthonous Complex to the Alcañices Syncline. The sampled volcanic body is a grey massive rhyolite with disseminated sulphides, the last causing a reddish colour of the rock when weathered. Colourless quartz crystals displaying fine examples of volcanic embayment have sizes up to 2 mm. An age of 494.1 ± 1.1 Ma was attained (lower Furongian) (SI-9A); nevertheless, the olistolith stratigraphic position, higher than fossiliferous Silurian (González Clavijo, 2006), precludes other explanation than a glided block of older vulcanite.

Sample RAB-01, located at the north of the Alcañices village, was sampled in a metric block of foliated rhyolitic pyroclastic tuff inside the lower part of the syn-orogenic San Vitero Fm. Structurally is placed in a duplex made of slices constituted by San Vitero and the sheared black Silurian unit at the base (Fig. 7A). The sample yields a 476.0 ± 1.5 Ma age (Floian) (SI-9B); but the position of the block, stratigraphically higher than the Silurian black unit dated by graptolites (González Clavijo, 2006, pers. com. Gutiérrez Marco, Sá, and Piçarra on this locality), excludes other plausible explanations as an interlayered pyroclastic flow, or a sill.

### 5.2 Olistoliths magmatic ages from references

In the Alcañices synform a quantity of vulcanite olistoliths has been identified; all of them of rhyolite to dacite composition, and often forming big clusters with a NW-SE attitude.

Previous research (González Clavijo et al., 2016) obtained an age of the Nuez olistolith (NUEZ-01; situation in Fig. 4), one of the major blocks forming a several kilometer long cluster included in an olistostrome inside the syn-orogenic Rábano Fm, towards the S of the synform. This block contains two volcanic facies: dacite lava and dacitic pyroclastic tuff (Ancochea et al. 1988), belonging the attained age to the latter. A LA-ICP-MS U-Pb in zircon concordant age of 497 ± 2 Ma (lowermost Furongian) was achieved, which was considered magmatic.

In the N of the same synform other volcanic body, Figueruela (COS-8; situation in Fig. 4), was dated by SHRIMP-II U-Pb analysis (Farias et al., 2014) and interpreted as a flow of dacitic lava interlayered in the Paraño Group of the Galicia Schistose Domain or Parautochthon *sensu lato*. A thorough field review of the area shows a major cluster of olistoliths mainly composed of dacite and rhyolite lavas and tuffs, but also containing quartzite and black lydite big blocks. In our reinterpretation the Figueruela dacite is an olistolith contained in a basal block-in-matrix unit placed below the San Vitero coherent primary unit and above the black Silurian condensed unit. In this section, parts of the block-in-matrix unit and the Silurian black sequence are sheared, forming a polygenetic mélange in the meaning proposed by Festa et al. (2019, 2020). Thus, in our general model, the Figueruela dacite belongs to the syn-orogenic LPa as proposed by González Clavijo et al. (2016). The SHRIMP U/Pb in zircon age is 488.7 ± 3.7 Ma (around the limit Furongian/Tremadocian) and is considered magmatic.

Between the Alcañices and Verín synforms, at the N of the Bragança Allochthonous Complex , other big volcanic body was dated by Farias et al. (2014) and named as the Soutelo rhyolite (COS-7; situation in Fig. 4). This sample was dated by the same analytical method than the Figueruela dacite yielding a 499.8 ± 3.7 Ma (upper Miaolingian). This massive rhyolitic lava was also included in the Paraño group and considered a volcanic event among the sedimentary sequence. Our field study disclosed the existence of a huge cluster of olistoliths of diverse lithologies as black lydite, grey quartzite, greywacke, limestone, rhyolitic lavas, and acidic pyroclastic tuffs, being the last two the most abundant types. Complementarily, this major block-in-matrix unit is placed on top of an intensely deformed condensed black Silurian unit (a tectonic mélange). For all these reasons we consider that the rhyolite volcanic body analysed in Soutelo is also an olistolith inside the syn-orogenic LPa.

### 5.3 The possible sources of the magmatic olistoliths are in the UPa

The UPa unit, as defined for Dias da Silva et al. (2014) below the Morais Complex, contains an Upper Cambrian to Silurian detrital sequence with minor limestones and interbedded voluminous volcanism (Pereira et al., 2000; 2006). The main volcanic events are, from bottom to top, Mora acid and basic volcanites (Dias da Silva, 2014; Dias da Silva et al., 2014; Díez-Montes et al., 2015); the traditionally named as Saldanha gneiss (Ribeiro, 1974; Ribeiro and Ribeiro, 2004; Pereira et la., 2006; Pereira et al., 2008) which actually is a rhyolitic dome composed by lavas and volcanic tuffs (Dias da Silva et al., 2014; Díez-Montes et al., 2015); and finally the big acid and basic volcanic half of the Volcano Siliceous Complex in the higher part of the UPa, also known as Peso Volcano-Sedimentary Complex (Ribeiro, 1974; Pereira et al., 2006; Dias da Silva et al., 2016; Díez-Montes et al., 2015). Previous isotopic research performed in some representative bodies of those volcanic rocks (MOR-18ZIR; SAL-1ZIR; PR-01; PR-02, situation on Fig. 4) at the E fringe of Morais Complex (Dias da Silva et al., 2014; Dias da Silva et al., 2016) yielded ages from uppermost Cambrian to Upper Ordovician (493,5±2 Ma to 457,7±7 Ma). These attained ages support that the polyphasic pervasive deformation underwent by the UPa has not greatly disrupted the original sedimentary architecture as the interlayered volcanic rocks kept the right chronological order (Dias da Silva et al., 2016; Díez-Montes et al., 2015). This published research was focused in obtaining magmatic ages of the studied rocks and lacks information on the inherited age signature in these rocks. Nevertheless, they were crucial to confirm that the UPa was the source of some if not all of the Cambro-Ordovician volcanic olistoliths in the LPa (González Clavijo et al., 2016), as the Nuez, Soutelo (COS-7) and Figueruela (COS-8) hectometer-size magmatic olistoliths.

The two new samples picked up in the NW Morais Complex UPa (P381 and P385) were analyzed for magmatic and inherited ages (Supplementary File; SI-7), thus defining the fingerprint of this possible source (see MDS process in Supplementary File). Sample P381 (situation in Fig. 4, coordinates in Table 1 and geochronology in Supplementary File) presented a youngest zircon age of 456 Ma and a youngest population (magmatic age) of 461 Ma (Darriwilian) (SI-7A). Although it was collected in a similar structural/stratigraphic position, sample P385 seems to be older, with the youngest zircon at 468 Ma and magmatic age of 475 Ma (Floian/Arenigian) (SI-7B). Ages of both rocks confirm the results obtained in previous studies, which have demonstrated a Middle-Upper Ordovician age for the Peso Fm. of the UPa (Dias da Silva et al., 2016). These new results also show that the UPa is the major source of the 440-475 Ma magmatic olistoliths in the LPa synorogenic basin, also supported by the age distribution plots and the MDS diagrams presented in this work (see discussion and Supplementary File)

## 6 Discussion

### 6.1 Structural and stratigraphic meaning of the Lower Parautochthon synorogenic basins

The studied samples containing Variscan zircons make possible to extend the LPa to areas bearing sequences pointing to a sedimentary environment (flyschoid with or without broken beds, block-in-matrix facies, olitostromes, slump folds) previously not openly stated as Variscan syn-orogenic deposits. From the eastern Bragança and Morais complexes rim area, where the LPa was defined (Dias da Silva et al., 2014; 2015; 2020), this unit may be spread by the S following the GTMZ edge through the Meirinhos (MEI-ZR-01 and CR-ZR-01) and W Mirandela (MIR-41, AD-PO-49, AD-PO-5 and AD-PO-57) zones to end in the Vila Pouca multiplex (AD-PO-48B) as represented in Figs. 2 and 4. Farther south, W of Vila Real town, in the Marão hills some structurally staked units contain sequences described by Pereira (1987) that mimic the LPa general model, with a lower condensed Silurian black unit (Campanhó) overlayered by flyschoid sequences (Mouquim and Canadelo) which have been lithologically correlated to some of the Alcañices zone LPa units (González Clavijo, 2006).

To the W of the Alcañices synform, at the N rim of the Bragança Complex, 3 samples picked up in the flyschoid sequence (EC-PO-293, GIM-ZR-01 and AD-PO-66), 2 ages obtained in volcanic olistoliths (EC-PO-337 and EC-PO-419) and 1 datum from references in other olistolith (COS-7, Farias et al., 2014), support the existence of the LPa rocks in several stacked slices as the Variscan syn-orogenic sequence (Tournaisian age or younger) holds upper Cambrian and Ordovician volcanic glided blocks (Fig. 9A), besides previously findings of graptolite-rich Silurian lydites (e.g. Meireles et al. 1999a, 1999b; Piçarra et al., 2006a, 2006b). A similar arrangement was unveiled in the Alcañices Synform from 2 new samples picked in olistoliths (PET-01 and RAB-01) plus 2 from references (NUEZ, González Clavijo et al., 2016 and COS-8, Farias et al., 2014) yielding upper Cambrian to Ordovician ages in blocks which are surrounded by the Upper Devonian to Mississippian syn-orogenic sequence, among other Lower-Ordovician-Lower Devonian fossil-bearing sedimentary olistoliths These two last zones, Alcañices and N Bragança, have continuity with the Nogueria Group at the Verín synform (Farias, 1990), which is the upper part of the originally defined group (Marquínez, 1984). In our field work, a coherent primary unit made of rhythms up to decimetre composed of phyllite and greywacke has been identified in several zones (Fig. 9B), but greenish fine litharenite thick beds are also present close to the town of Verín. Block-in-matrix lensoidal bodies enclosing native and exotic blocks were also observed (Fig. 9C and D), some of them big enough to be considered olistoliths (mainly made of quartzite, black lydite, black limestone, and acidic vulcanite, both lava and tuff). Towards the base, black lydite and ampelite beds are frequent and they are strongly sheared, thus forming a tectonic mélange involving syn-orogenic and black Silurian rocks (Fig. 9E). It can be also envisaged as a very complex arrangement of minor tectonic slices forming an intricate multiplex system, where the horses repeat both stratigraphic units (Silurian and syn-orogenic). In the most oriental part of the SW limb (Fig. 2 and cross section 3 in Fig. 3) this unit share the same characteristics but some observed olistholits are clearly made of UPa rocks, as they show the materials and polyphasic pervasive deformation characteristic of the tectonically overlaying unit (Fig. 9F, G and H). In that Portuguese section, this unit has been named Lower Schist Formation and according Pereira et al. (2000) is composed of phyllite and greywacke in fine rhythms, being the last very rich in plagioclase, thus supporting a source area rich in volcanic rocks. According the here adopted terminology (Festa et al., 2019, 2020) its basal stretch is made of several tectonic slices mixing the block-in-matrix sequence and the black Silurian sheared rocks, thus being considered a polygenetic mélange.

This work field revision on the Verín synform geology allows proposing in addition that the core of this late Variscan synform is the enlargement of the UPa for several reasons:

i) the map continuity with the Bragança Complex UPa (Fig. 2);
ii) the existence of a major thrust underlying the unit (Farias, 1990), which is here reinterpreted as the MTMT following Dias da Silva (2014) 7proposal;
iii) it is made of low metamorphic grade pervasively deformed detrital rocks like the sequence forming the UPa in Morais and Bragança (Nuño Ortea et al., 1981; Alonso, J.L, et al., 1981; Farias, 1990);
iv) it contains volcanic interbedded bodies (Nuño Ortea et al., 1981; Alonso, J.L, et al., 1981; Farias, 1990; Valverde Vaquero et al., 2007);
v) a continuous white quartzite bed displaying the synform (Fig. 2) have the same lithology and shows spatial continuity with the Algoso Fm in Portugal, which is considered an Armorican type Lower Ordovician quartzite in the UPa (Dias da Silva, 2014; Dias da Silva et al., 2016); and
vi) a volcanic body placed above the Lower Ordovician quartzite in the Verín synform, the Navallo traquite, has a radiometric age yielding 439,6±5 Ma (Uppermost Ordovician to Silurian) (Valverde Vaquero et al., 2007) an age younger but coherent to the attained in the eastern Morais Complex UPa (Peso Fm., see above).

To the N, in the Cabo Ortegal Complex, the Rio Baio thrust sheet (Marcos et al., 2002) is structurally placed under the allochthonous units and has been correlated to the Schistose Domain in Órdenes, Bragança and Morais complexes (Farias et al., 1987; Ribeiro et al.,1990; Martínez Catalán et al., 1997). The internal structure of Rio Baio slice is complex, holding a greenschist facies detrital sequence which includes folded quartzites and volcanic rocks (Arce Duarte and Fernández Tomás, 1976; Arce Duarte et al., 1977; Fernández Pompa and Piera Rodríguez, 1975; Fernández Pompa et al., 1976; Marcos and Farias, 1997), namely the Loiba dacites, Costa Xuncos rhyolites and Queiroga rhyolites, (Arenas, 1984, 1988; Ancochea et al., 1988). The Rio Baio sequence was considered Silurian by the fossiliferous content of some levels (Matte, 1968; Romariz, 1969; Iglesias and Robardet, 1980; Piçarra et al., 2006); nevertheless, a field reappraisal considered those Silurian levels placed below the Rio Baio unit (Valverde Vaquero et al., 2005). The base of the Rio Baio thrust sheet is detached from the autochthonous CIZ by a thrust fault developed in black Silurian rocks (here inferred as the LPBD). Immediately above the LPBD, a low metamorphic grade detrital sequence is exposed at the coast line, where the Picón-2 sample was collected (Figs. 2, 3 and 4) and the detrital zircon study supports the Variscan syn-orogenic origin of this sequence (see above) and consequently we ascribe it to the LPa. Thus at the base of the Cabo Ortegal Complex, in the Rio Baio tectonic unit, the UPa/LPa division is also present, with a thin LPa structural unit placed onto a tectonic mélange developed in the Silurian rocks; while the rest of the Rio Baio thrust sheet is here proposed as the pre-orogenic UPa unit in the Cabo Ortegal Complex on base of lithological correlation, metamorphic grade and deformation. An isotopic age attained by Valverde Vaquero et al. (2005) in the Queiroga alkaline rhyolite (475±2 Ma - Tremadocian) reinforces this ascription for similarity with other acidic volcanites in the Morais Complex UPa (Dias da Silva, 2014; Dias da Silva et al., 2014; Dias da Silva et al., 2016; this work data).

Based on the results of the 17 samples here presented plus previous research data we propose the LPa Variscan syn-orogenic structural unit is general in the NW Iberia, forming a tectonic carpet which separates the GTMZ and the CIZ. Nevertheless, as can be seen in Figs. 2 and 3, the LPa is not observed in some reaches of the zones limit for different reasons. In some parts Variscan granitoids have intruded, erasing the previous geological information. Between the Cabo Ortegal and the Bragança complexes and in the northern Porto sector the available data from references not conclusively support the existence of syn-orogenic sequences which could be endorsed to the LPa; and no detrital zircon study oriented to this target have been performed yet, being a future aim of the research team. Finally, it is worth to highlight the existence of a detached remnant of LPa sequences (San Clodio series) preserved at the core of a late Variscan syncline in the autochthonous side of the limit (CIZ) not far away from the LPa/CIZ boundary.

The strongly deformed black Silurian condensed sequence present at the base of the every LPa tectonic slice, and frequently separated from the syn-orogenic sequence for a thrust fault, must be considered a tectonic mélange in the meaning proposed by Festa et al. (2019; 2020) as it also incorporates tectonic blocks and olistoliths from the base of the syn-orogenic sequences; so, when the shearing band incorporates glided blocks (Figs. 7 and 9) it could be better classified as a polygenetic mélange (Festa et al., 2019; 2020). Thus we envisage this thrusting structure as a mixing unit sharing rocks of the LPa and the Autochthon, where the Silurian parts could have been scraped off from the CIZ local uppermost sequence at the orogenic time, a mechanism suggested by Ogata et al. (2019), Semeraglia et al. (2019) and Hajna et al. (2019) for the mélanges formation.

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This offscraping mechanism is supported in the study area by the Silurian rocks found in the autochthonous unit (CIZ) at the eastern part of the Alcañices Synform (González Clavijo, 2006).

### 6.2 Source-areas of the siliciclastic rocks and olistoliths in the Lower Parautochthon: MDS results

We used Multidimentional Scaling (MDS) (ISOPLOT-R by Vermeech, 2018) to compare the new and the already published data on the zircon age populations of the NW Iberia synorogenic basins, with potential sources within the Iberian Massif terranes (see Supplementary File for more details, and complete U-Pb age datasets in Supplementary Tables 18 and 19). This approach has proven successful in the improvement of paleogeographic reconstruction models in the southwestern branch of the Iberian Variscan belt (Pereira et al., 2020a; 2020b) where the zircon age fingerprinting of the possible sedimentary sources and the Devono-Carboniferous synorogenic marine basins have shown these basins were fed by sediments from both continental margins, Laurussia and Gondwana, and from a “missing” Variscan volcanic arc (Pereira et al., 2012).

In this study, the zircon age data used to represent the possible source areas of the synorogenic marine basins of NW Iberia is a data selection of published U-Pb ages of detrital zircons of pre-Upper Devonian siliciclastic rocks of the NW Iberian Autochthon and Allochthonous Complexes. The geochronological data gathered by Puetz et al. (2018) and Stephan et al. (2018) (reference samples in Supplementary Table 18) were used in combination to have the best quantity and quality of data. We have performed a quality test to the U-Pb isotopic data in each sample, recalculating all the zircon ages following the procedure used in our samples. This dataset is used to fingerprint the source areas using MDS and works as a tool to plot our team age data collection of the synorogenic siliciclastic rock samples, which was expanded in this work from 13 to a total of 24 samples. We have also included new zircon age data on volcanic rocks from the UPa (2 samples) and from large olistoliths in the LPa (4 samples) to compare their age spectra with the detrital zircon samples, thus tracing the source areas for some of the large olistoliths and the flysch sequence.

The age data of the possible source areas was selected according a conceptual paleogeographic model for the Upper Devonian-lower Carboniferous (as provided in Dias da Silva et al., 2015 and Martínez Catalán et al., 2016). Following the reasoning explained in Supplementary File, we define Source A samples as representative of the peripheral bulge developed in the Autochton (CIZ, WALZ-CZ and OMZ) and the UPa slice as the most continental section of North-central Gondwana margin; Source B reflects the NW Iberian Allochthon (GTMZ), defined as an accretionary complex emplaced onto the autochthon in the Devonian-Carboniferous using the Parautochthon as the lower tectonic sheet. We highlight that although the UPa is in Source A, it could have been at either side of the synorogenic basin margins, as belonging to the peripheral bulge in early Variscan times (Late Devonian), or to the GTMZ basal tectonic sheet in the early Carboniferous, as the tectonic front moved towards inland Gondwana. In this way, Source A samples were grouped by stratigraphic age, considering that the general stratigraphy of the Autochthon and UPa was not substantially shuffled by major Variscan thrust zones as in the case of the GTMZ allochthons. In Source B, the GTMZ Allochthonous complexes were separated according to their tectono-metamorphic

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unit/domain with all samples ranging from Ediacaran to Lower Ordovician stratigraphic ages and belonging to the Galician allochthonous units (Malpica-Tuy, Ordenes and Cabo Ortegal complexes).

Using the MDS diagram with both potential sources as the base of our provenance study, we have plotted the new and published zircon age populations of the synorogenic siliciclastic rocks, adding the new magmatic and inherited ages of the Middle Ordovician-Silurian volcanic rocks collected as olistoliths in the LPa and in the upper stratigraphic units of the UPa.

The final MDS plot (Fig. 10, Supplementary File for more detailed information) shows two main age clusters: Cluster 1 – "Upper Parautochthon Middle Ordovician-Silurian volcanism" characterized by synorogenic sediments with high abundance of Cambrian and Ordovician zircons, namely a high concentration of Middle to Upper Ordovician ages and minor amounts of Silurian and Devonian ages (Fig. 11); Cluster 2 – "Multiple Gondwana-derived Sources" includes age populations with a wide variety of sub-clusters (Groups 1 to 7, Figs. 10 and 12; Supplementary File), including the Autochthon and the UPa (Source A), and the Allochthonous complexes (Source B). The defined groups show direct relations with the most probable sources (A and/or B), but they also represent different grades of sediment mixing and recycling (Fig. 10).

The analysis of the MDS diagram (Fig. 10) and age distribution plots (Figs. 11 and 12) demonstrated that there is no specific pattern in the provenance of sediments in time and space. It is interesting to see dramatic provenance changes along and across the same stratigraphic units, sometimes with samples collected in different beds that are a few centimeters apart (e.g. samples MIR-41 and AD-PO-49). In this way, we checked that zircon provenance varies substantially or circumstantially, with sediments coming for both sources at the same time and/or in different sectors of the marine synorogenic basins preserved in the LPa. Another interesting aspect is the representation mixing between age groups, with sediment recycling leading to dilution of sources towards more typical Gondwana (e.g. Group 7 and Cluster 1 showing a trend to Group 5), or reversely with younger samples falling closer to the allochthonous complexes (e.g. trend in Group 7, from samples SO-14, SO-1 and SO-2 towards the Upper Allochthon reference population).

These fluctuations reveal drastic variations of the topographic highs surrounding the synorogenic basin at both margins (accretionary complex and peripheral bulge) in the Upper Devonian-lower Carboniferous (Fig. 13). The tectonic activity that controls the basin shape and sedimentation was also capable to trigger highly erosive, large-scale mass-wasting that forms the large olistolith-bearing BIMF deposits. The synorogenic marine sediments (cohesive flysch and BIMF) were gradually incorporated at the base of the accretionary wedge as a tectonic carpet, forming polygenic mélanges. The rapid frontal accretion of trench turbidites (Kusky et al., 2020) allowed the fast exhumation of the marine sediments, leading to their recycling within the basin (wild-flysch).

### 6.3 Origin of Varican zircons

One contrasting aspect of NW Iberia synorogenic basins with other Variscan belt sectors, such as SW Iberia (e.g. Pereira et al 2020a, 2020b; Pérez-Cáceres et al., 2017), is the lack of Variscan ages in the populations in our study case. Only 14 samples out of 24 have a minor population of Variscan zircons, comparing with the predominant Variscan zircon populations in most of the synorogenic formations in SW Iberia.

The synorogenic Variscan zircons are represented in all studied formations of the LPa, independently of the age cluster they belong (the clusters mostly define the “old” zircon age population patterns) (Figs. 11 and 12). Because there are no evidences of syn-sedimentary vulcanism associated to the synorogenic marine basins of NW Iberia (it is amagmatic, whereas in SW Iberia the vulcanism is persistent; Oliveira et al., 2019a, 2019b), one must explain the origin of the (scarce) Variscan zircon populations in the LPa.

To verify the sources for the Variscan zircons in the studied basins, we had to check the main zircon forming events represented in the Allochthonous Complexes (GTMZ) and in the underlying autochthon (CIZ, WALZ-CZ and OMZ), and in other Variscan sectors. The oldest Variscan zircon populations in the LPa range from c.a. 400 to 380 Ma, which can be related to the HT(HP) metamorphism in the Upper Allochthon (Gómez-Barreiro et al., 2006, 2007). A second younger age group, between 380-370 Ma can have their origin in the metamorphic zircons of the Middle Allochthon (Pin et al. 2006; Arenas et al., 2007; Arenas and Sánchez-Martínez, 2015; Santos Zalduegui et al., 1996; and references within). In the same way, the age group including zircon ages in the range 370-360 Ma can have their source in the HT(HP) metamorphic rocks of the Lower Allochthon (Abati et al., 2010; Díez Fernández et al., 2011; Santos Zalduegui et al., 1995). While these “oldest” Variscan ages are found in a relatively small number in the Allochthonous Complexes (Source B), younger age groups can be also identified in the underlying autochthon. In this manner, ages in the range of 340-320 Ma are commonly associated to a HT-LP regional tectono-metamorphic event with magmatic flare-ups at 340, 335 and 320 Ma, that affects both autochthonous and allochthonous domains in Iberia (ZCI, WALZ, OMZ and ZGTM) (Dias da Silva et al., 2018; Díez Férnandez and Pereira, 2016, Díez Fernández et al., 2017; Gutierrez-Alonso et al., 2018; López-Moro et al., 2017; Martínez Catalán et al., 2003). So, the most probable source for this zircon ages lye in the autochthon (Source A) and GTMZ (Source B).

On the other hand, the 370-340 Ma age spectrum is not very easy to explain because it is not easily found in the nearby sources. In other sectors of the Variscan belt there are several evidences of explosive vulcanism synchronous with the synorogenic sedimentation, such as in the South Portuguese Zone or in Ossa Morena Zone (e.g. Tournaisian-Visean magmatism, e.g. Pereira et al. 2020a; Oliveira et al., 2019a). This kind of magmatism can provide a shower of some airborne zircons into this relatively far basin as the ash cloud falls (Fig. 13). This explanation can also be used to other erratic zircon ages, with (“missing”) magmatic arcs that were active during the Upper Devonian (Pereira et al., 2012). Also, HT-LP metamorphic events that are described in the French Massif Central (Gèret Dome, c.a. 365 Ma, Faure et al. 2009) which cut the root zone of the GTMZ accretionary complex, can be considered as a source. Although this zone is currently far away, they could have been closer to the synorogenic basins in the Upper Devonian- early Carboniferous.

## 7 Conclusions

We present in this paper new results from field and geochronology studies on the Variscan orogeny (390-300 Ma) foreland marine basins of NW Iberia, that rim the unrooted accretionary complexes of the Galicia-Trás-os-Montes Zone (GTMZ), and outline its boundary with the structurally underlying autochthon, the Central Iberian Zone (CIZ).

The relationship of this foreland marine basin with the structurally underlying and overlying units has been successfully established in the revised sectors of NW Iberia. We reveal  that both parautochthonous units of the GTMZ, as defined in the eastern rim of the Morais and Bragança complexes, cover a larger area than previously estimated, being exposed from Cabo Ortegal (NW Spain) to Trás-os-Montes (NE Portugal). The existence of a preorogenic highly folded Upper Parautochthon (UPa) and an imbricated thrust-complex Lower Parautochthon (LPa) composed of slices of Devono-Carboniferous turbidites and tectonically scrapped autochthonous Silurian strata becomes a general architecture for the NW Iberia. Regional tectonic and stratigraphic aspects show that the LPa is a syn-orogenic basin that was gradually incorporated into the base of the accretionary wedge while it was expanding towards Gondwana, defining a continuous tectonic carpet at the base of the GTMZ. A detailed analysis of the stratigraphic and tectonic aspects of the synorogenic flysch in the LPa highlight the abundance and the importance of large-scale mass wasting deposits in the sequence. These deposits originated Block-in-Matrix formations (BIMF), sedimentary mélanges with large olistoliths with exotic natures (with origin in the accretionary wedge and in the autochthon exposed in the forebulge) surrounded by a chaotic matrix with slump folds and broken beds of the flysch sequence. These deposits were triggered by an intense tectonic activity within the foreland basin and at both margins. The BIMF are frequently tectonized, forming thrust multiplexes with polygenic mélanges and tectonically scrapped autochthonous Silurian black shales at the base.

The zircon geochronology of the LPa siliciclastic rocks, and magmatic rocks from the UPa and the LPa (olistoliths), has constrained the provenance of the sediments and blocks in this sector of the Variscan foreland basin. Our study confirmed the synorogenic nature of the LPa stratigraphic units, all presenting Variscan zircons with Famennian to Serpukhovian ages, with possible sources in the allochthonous complexes (390-365 Ma), in the HT-LP metamorphic domes exposed in the root zone of the GMTZ (365 Ma) and in the autochthon (340-320 Ma), or they can be airborne zircons carried in ash clouds coming from the Variscan magmatic arc(s) (365-340 Ma).

The older zircon age populations were compared with reference samples from possible source-areas using fingerprinting with Multidimentional Scaling (MDS). The associations of the synorogenic sediments with the reference populations, including the magmatic and inherited ages now obtained in the Middle Ordovician-Silurian volcanic rocks of the UPa (source) and LPa (olistoliths), allowed direct source-to-sink relationships of the foreland basin with the accretionary complex (GTMZ) and the peripheral bulge (autochthon). The MDS analysis demonstrates intrabasin sediment recycling and mixing of sources in time and space, highlighting the tectonic instabilities within the basin and in its margins, the migration of the depocenter towards inland Gondwana, and gradual incorporation of the foreland basin in the accretionary wedge that led its exhumation and recycling.

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## Data availability

Data is available in Supplementary files, uploaded with this manuscript.

## Author contribution

Emílio González Clavijo (EGC), Ícaro Dias da Silva (IDS), José Martínez Catalán (JMC), Juan Gómez Barreiro (JGB), Gabriel Gutíerrez Alonso (GGA) and Alejandro Díez Montes (ADM) have participated in the selection and preparation of the geochronology samples used in this work.

IDS, JMC, GGA, Mandy Hoffmann (MH), Andreas Gärtner (AG) and Ulf Linnemann (UL) have contributed in the of U-Pb-Th isotopic analysis and age data processing using LA-ICP-MS in the Senckenberg Geochronology labs in Dresden.

EGC and IDS were responsible by the elaboration of the manuscript, supplements, and illustrations, including field and microscope photos.

IDS was responsible by the geochronology analysis of the collected samples, the elaboration of the geochronological database and data quality test, and by the statistical analysis and sink-to-source correlation using Multidimentional Scaling.

## Competing interests

There are no competing interests.

## References

Abati, J., Gerdes, A., Fernández Suárez, J., Arenas, R., Whitehouse, M. J., and Díez Fernández, R.: Magmatism and early-Variscan continental subduction in the northern Gondwana margin recorded in zircons from the basal units of Galicia, NW Spain, Geological Society of America Bulletin, 122, 219-235, 2010, doi: 10.1130/b26572.1

Alcock, J. E., Martínez Catalán, J. R., Rubio Pascual, F. J., Díez Montes, A., Díez Fernández, R., Gómez Barreiro, J., Arenas, R., Dias da Silva, Í., and González-Clavijo, E.: 2-D thermal modeling of HT-LP metamorphism in NW and Central Iberia: Implications for Variscan magmatism, rheology of the lithosphere and orogenic evolution, Tectonophysics, 657, 21-37, 2015, doi: 10.1016/j.tecto.2015.05.022

Aldaya, F.; Carls, P.; Martínez-García, E., and Quiroga, J.L.,: Nouvelles précisions sur la série de San Vitero (Zamora, nord-oueste de l´Espagne), C. R. Acad. Sci. Paris, t. 283, série D, 881-883, 1976.

Alonso Alonso, J.L., Delgado Gutiérrez, C., Zubieta Freira, J.M., Pérez Rojas, A., Ferragne, A., and Rúiz Díaz, C.: Mapa Geológico de España, E. 1:50.000 y Memoria, Hoja 265-Laza, Segunda Serie, IGME, Madrid, 26 p, 1981

Alonso, J. L., Marcos, A., Villa, E., Súarez, A., Merino-Tomé, O. A., and Fernández, L. P.: Mélanges and other types of block-in-matrix formations in the Cantabrian Zone (Variscan Orogen, northwest Spain): origin and significance, International Geology Review, 57, 563-580, 2015, doi: 10.1080/00206814.2014.950608

Ancochea, E., Arenas, R., Brãdle, J.L., Peinado, M., and Sagredo, J.: Caracterización de las rocas metavolcánicas silúricas del Noroeste del Macizo Ibérico. Geosci. Aveiro 3 (fasc. 1–2), 23–34, 1988.

Antona, J.F., and Martínez Catalán, J.R.: Interpretación de la Formación San Vitero en relación con la Orogenia Hercínica, Cuad. Lab. Xeol. Laxe 15, 257–269, 1990.

Arce Duarte, J.M., and Fernández Tomás, J.: Mapa Geológico de España. Escala 1:50.000, Hoja 8 (7-3), Vivero. Segunda Serie, Mapa y Memoria, IGME, Madrid, 45 p, 1976.

Arce Duarte, J.M., Fernández Tomás, J. and Monteserín López, V.: Mapa Geológico de España. Escala 1:50.000, Hoja 7 (7-2), Cillero. Mapa y Memoria, Instituto Geológico Minero España, Madrid, 47 p, 1977.

Arenas, R.: Características y significado del volcanismo ordovícico-silúrico de la serie autóctona envolvente del Macizo de Cabo Ortegal (Galicia, NW España). Revista Materiales Procesos Geológicos, 11, 135-144, 1984.

Arenas, R.: Evolución petrológica y geoquímica de la Unidad alóctona inferior del Complejo metamórfico básico-ultrabásico de Cabo Ortegal (Unidad de Moeche) y del Silúrico paraautóctono, Cadena Herciniana Ibérica (NW de España). Corpus Geologicum Gallaeciae, 4, 545 pp, 1988.

Arenas, R., Abati, J., Catalán, J. R. M., García, F. D., and Pascual, F. J. R.: P-T evolution of eclogites from the Agualada Unit (Ordenes Complex, northwest Iberian Massif, Spain): Implications for crustal subduction, Lithos, 40, 221-242, 1997, doi: 10.1016/S0024-4937(97)00029-7

Arenas, R., Martínez Catalán, J. R., Sánchez Martínez, S., Díaz García, F., Abati, J., Fernández-Suárez, J., Andonaegui, P., and Gómez Barreiro, J.: Paleozoic ophiolites in the Variscan suture of Galicia (northwest Spain): Distribution, characteristics and meaning. In: 4D Framework of Continental Crust, Hatcher Jr., R. D., Carlson, M. P., McBride, J. H., and Martínez Catalán, J. R. (Eds.), Geological Society of America, 2007.

Arenas, R., Pascual, F. J. R., Garcia, F. D., and Catalan, J. R. M.: High-pressure micro-inclusions and development of an inverted metamorphic gradient in the Santiago Schists (Ordenes Complex, NW Iberian Massif, Spain): evidence of subduction and syncollisional decompression, Journal of Metamorphic Geology, 13, 141-164, 1995, doi: 10.1111/j.1525-1314.1995.tb00211.x

Arenas, R. and Sanchez-Martinez, S.: Variscan ophiolites in NW Iberia: Tracking lost Paleozoic oceans and the assembly of Pangea, Episodes, 38, 315-333, 2015, doi: 10.18814/epiiugs/2015/v38i4/82427

Azor, A., Dias da Silva, Í., Gómez Barreiro, J., González-Clavijo, E., Martínez Catalán, J. R., Simancas, J. F., Martínez Poyatos, D., Pérez-Cáceres, I., González Lodeiro, F., Expósito, I., Casas, J. M., Clariana, P., García-Sansegundo, J., and Margalef, A.: Deformation and Structure. In: The Geology of Iberia: A Geodynamic Approach: Volume 2: The Variscan Cycle, Quesada, C. and Oliveira, J. T. (Eds.), Springer International Publishing, Cham, 2019, doi: 10.1007/978-3-030-10519-8_10

Ballèvre, M., Martínez Catalán, J. R., López Carmona, A., Pitra, P., Abati, J., Díez Fernández, R., Ducassou, C., Arenas, R., Bosse, V., Castiñeiras, P., Fernández-Suárez, J., Gómez Barreiro, J., Paquette, J. L., Peucat, J. J., Poujol, M., Ruffet, G., and Sánchez Martínez, S.: Correlation of the nappe stack in the Ibero-Armorican arc across the Bay of Biscay: a joint French-Spanish project, Geological Society, London, Special Publications, 405, 77-113, 2014, doi: 10.1144/sp405.13

Barrera Morate, J.L., Farias Arquer, P., González Lodeiro, F. et al.: Mapa Geológico Nacional E. 1:200 000, 17-27, Orense–Verín. Instituto Geológico y Minero de España, Madrid, 1989.

Braid, J. A., Murphy, J. B., Quesada, C., and Mortensen, J.: Tectonic escape of a crustal fragment during the closure of the Rheic Ocean: U–Pb detrital zircon data from the Late Palaeozoic Pulo do Lobo and South Portuguese zones, southern Iberia, Journal of the Geological Society, 168, 383-392, 2011, doi: 10.1144/0016-76492010-104

Bütler, E., Winkler, W., and Guillong, M.: Laser ablation U/Pb age patterns of detrital zircons in the Schlieren Flysch (Central Switzerland): new evidence on the detrital sources, Swiss Journal of Geosciences, 104, 225, 2011, doi: 10.1007/s00015-011-0065-1

Chiocci, F. L. and Casalbore, D.: Reprint of Unexpected fast rate of morphological evolution of geologically-active continental margins during Quaternary: Examples from selected areas in the Italian seas, Marine and Petroleum Geology, 87, 148-156, 2017, doi: https://doi.org/10.1016/j.marpetgeo.2017.06.014

Coleman, J. M. and Prior, D. B.: Mass Wasting on Continental Margins, Annual Review of Earth and Planetary Sciences, 16, 101-119, 1988, doi: 10.1146/annurev.ea.16.050188.000533

DeCelles, P. G.: Foreland basin systems revisited: Variations in response to tectonic settings, Tectonics of sedimentary basins: Recent advances, 2012. 405-426, 2012, doi: https://doi.org/10.1002/9781444347166.ch20

Dias da Silva, Í.: Geología de las Zonas Centro Ibérica y Galicia – Trás-os-Montes en la parte oriental del Complejo de Morais, Portugal/España, Instituto Universitario de Geología "Isidro Parga Pondal" - Área de Xeoloxía e Minería do Seminario de Estudos Galegos, Coruña, 2014.

Dias da Silva, Í., Díez Fernández, R., Díez-Montes, A., González Clavijo, E., and Foster, D. A.: Magmatic evolution in the N-Gondwana margin related to the opening of the Rheic Ocean—evidence from the Upper Parautochthon of the Galicia-Trás-os-Montes Zone and from the Central Iberian Zone (NW Iberian Massif), International Journal of Earth Sciences, 105, 1127-1151, 2016, doi: 10.1007/s00531-015-1232-9

Dias da Silva, Í., González Clavijo, E., and Díez-Montes, A.: The collapse of the Variscan belt: a Variscan lateral extrusion thin-skinned structure in NW Iberia, International Geology Review, doi: 10.1080/00206814.2020.1719544, 2020. 1-37, 2020, doi: 10.1080/00206814.2020.1719544

Dias da Silva, Í., Linnemann, U., Hofmann, M., González-Clavijo, E., Díez-Montes, A., and Martínez Catalán, J. R.: Detrital zircon and tectonostratigraphy of the Parautochthon under the Morais Complex (NE Portugal): implications for the Variscan accretionary history of the Iberian Massif, Journal of the Geological Society, 172, 45-61, 2015, doi: 10.1144/jgs2014-005

Dias da Silva, Í., Pereira, M. F., Silva, J. B., and Gama, C.: Time-space distribution of silicic plutonism in a gneiss dome of the Iberian Variscan Belt: The Évora Massif (Ossa-Morena Zone, Portugal), Tectonophysics, 747-748, 298-317, 2018, doi: 10.1016/j.tecto.2018.10.015

Dias da Silva, Í., Valverde-Vaquero, P., González-Clavijo, E., Díez-Montes, A., and Martínez Catalán, J. R.: Structural and stratigraphical significance of U–Pb ages from the Mora and Saldanha volcanic complexes (NE Portugal, Iberian Variscides), Geological Society, London, Special Publications, 405, 115-135, 2014, doi: 10.1144/sp405.3

Dickinson, W. R. and Valloni, R.: Plate settings and provenance of sands in modern ocean basins, Geology, 8, 82-86, 1980, doi: 10.1130/0091-7613(1980)8<82:psapos>2.0.co;2

Díez Fernández, R., Martínez Catalán, J. R., Arenas Martín, R., and Abati Gómez, J.: Tectonic evolution of a continental subduction-exhumation channel: Variscan structure of the basal allochthonous units in NW Spain, Tectonics, 30, 1-22, 2011, doi: 10.1029/2010TC002850

Díez Fernández, R., Martínez Catalán, J. R., Gerdes, A., Abati, J., Arenas, R., and Fernández-Suárez, J.: U-Pb ages of detrital zircons from the Basal allochthonous units of NW Iberia: Provenance and paleoposition on the northern margin of Gondwana during the Neoproterozoic and Paleozoic, Gondwana Research, 18, 385-399, 2010, doi: 10.1016/j.gr.2009.12.006

Díez Fernández, R., Parra, L. M. M., and Rubio Pascual, F. J.: Extensional flow produces recumbent folds in syn-orogenic granitoids (Padrón migmatitic dome, NW Iberian Massif), Tectonophysics, 703-704, 69-84, 2017, doi: https://doi.org/10.1016/j.tecto.2017.03.010

Díez Fernández, R. and Pereira, M. F.: Extensional orogenic collapse captured by strike-slip tectonics: Constraints from structural geology and UPb geochronology of the Pinhel shear zone (Variscan orogen, Iberian Massif), Tectonophysics, 691, 290-310, 2016, doi: 10.1016/j.tecto.2016.10.023

Díez-Montes, A., González Clavijo, E., Dias da Silva, Í., Gómez Barreiro, J., Martínez Catalán, J. R., and Castiñeiras, P.: Geochemical Evolution of Volcanism during the Upper Cambrian- Ordovician Extension of the North Gondwana Margin, Alfragide, 2015, 54-57.

Ducassou, C., Poujol, M., Ruffet, G., Bruguier, O., and Ballèvre, M.: Relief variation and erosion of the Variscan belt: detrital geochronology of the Palaeozoic sediments from the Mauges Unit (Armorican Massif, France), Geological Society, London, Special Publications, 405, 137-167, 2014, doi: 10.1144/sp405.6

Eyles, N.: Marine debris flows: Late precambrian "tillites" of the Avalonian-Cadomian orogenic belt, Palaeogeography, Palaeoclimatology, Palaeoecology, 79, 73-98, 1990, doi: https://doi.org/10.1016/0031-0182(90)90106-H

Farias, P., Casado, B. O., Marcos, A., Ordóñez, A. R., and Fanning, C.: U-Pb zircon SHRIMP evidence for Cambrian volcanism in the Schistose Domain within the Galicia-Trás-os. Montes Zone (Variscan Orogen, NW Iberian Peninsula), Geologica Acta, 12, 209-218, 2014, doi: https://doi.org/10.1344/GeologicaActa2014.12.3.3

Farias, P., Gallastegui, G., González-Lodeiro, F., Marquínez, J., Martín Parra, L. M., Martínez Catalán, J. R., de Pablo Maciá, J. G., and Rodríguez Fernández, L. R.: Aportaciones al conocimiento de la litoestratigrafía y estructura de Galicia Central, Memórias da Faculdade de Ciências da Universidade do Porto, 1, 411-431, 1987.

Farias, P.: La Geología de la región del sinforme de Verín (Cordillera Herciniana, NW de España), Instituto Universitario de Geología "Isidro Parga Pondal" - Área de Xeoloxía e Minería do Seminario de Estudos Galegos, La Coruña, 1990.

Faure, M., Lardeaux, J.-M., and Ledru, P.: A review of the pre-Permian geology of the Variscan French Massif Central, Comptes Rendus Geoscience, 341, 202-213, 2009, doi: 10.1016/j.crte.2008.12.001

Fernández Pompa, F., and Monteserín López, V.: Mapa Geológico de España. Escala 1:50.000, Hoja 7 (6-3), Cedeira. Mapa y Memoria, Instituto Geológico Minero España, Madrid, 73 p, 1976.

Fernández Pompa, F., and Piera Rodríguez, T.: Mapa Geológico de España. Escala 1:50.000, Hoja 22 (6-4), Puentedeume. Mapa y Memoria, Instituto Geológico Minero España, Madrid, 45 p, 1975.

Festa, A., Ogata, K., and Pini, G. A.: Polygenetic mélanges: a glimpse on tectonic, sedimentary and diapiric recycling in convergent margins, Journal of the Geological Society, 177, 551-561, 2020, doi: 10.1144/jgs2019-212

Festa, A., Ogata, K., Pini, G. A., Dilek, Y., and Alonso, J. L.: Origin and significance of olistostromes in the evolution of orogenic belts: A global synthesis, Gondwana Research, 39, 180-203, 2016, doi: 10.1016/j.gr.2016.08.002

Festa, A., Pini, G. A., Ogata, K., and Dilek, Y.: Diagnostic features and field-criteria in recognition of tectonic, sedimentary and diapiric mélanges in orogenic belts and exhumed subduction-accretion complexes, Gondwana Research, 74, 7-30, 2019, doi: https://doi.org/10.1016/j.gr.2019.01.003

Franke, W. and Engel, W.: Synorogenic sedimentation in the Variscan Belt of Europe, Bulletin de la Société Géologique de France, II, 25-33, 1986, doi: 10.2113/gssgfbull.II.1.25

Garzanti, E., Doglioni, C., Vezzoli, G., and Andò, S.: Orogenic Belts and Orogenic Sediment Provenance, The Journal of Geology, 115, 315-334, 2007, doi: 10.1086/512755

Gil Ibarguchi, J. I.: Petrology of jadeite metagranite and associated orthogneiss from the Malpica-Tuy allochthon (Northwest Spain), European Journal of Mineralogy, 7, 403-416, 1995, doi: 10.1127/ejm/7/2/0403

Gil Ibarguchi, J. I. and Dallmeyer, R. D.: Hercynian blueschist metamorphism in North Portugal: tectonothermal implications, Journal of Metamorphic Geology, 9, 539-549, 1991, doi: 10.1111/j.1525-1314.1991.tb00547.x

Gómez Barreiro, J.: La Unidad de Fornás: Evolución tectonometamórfica del SO del Complejo de Órdenes, Instituto Universitario de Geología "Isidro Parga Pondal" - Área de Xeoloxía e Minería do Seminario de Estudos Galegos, Coruña, 2007.

Gómez Barreiro, J., Martínez Catalán, J. R., Arenas, R., Castiñeiras, P., Abati, J., Díaz García, F., and Wijbrans, J. R.: Tectonic evolution of the upper allochtonon of the Órdenes complex (Northwestern Iberian Massif): Structural constraints to a poligenic peri-Gondwanan terrane, Geologic Society of America - Special paper, 423, 315-332, 2007, doi: 10.1130/2007.2423(15)

Gómez Barreiro, J., Wijbrans, J. R., Castiñeiras, P., Martínez Catalán, J. R., Arenas, R., Díaz García, F., and Abati, J.: 40Ar/39Ar laserprobe dating of mylonitic fabrics in a polyorogenic terrane of NW Iberia, Journal of the Geological Society, 163, 61-73, 2006, doi: 10.1144/0016-764905-012

González Clavijo, E.: La Geología del sinforme de Alcañices, Oeste de Zamora, Instituto Universitario de Geología "Isidro Parga Pondal" - Área de Xeoloxía e Minería do Seminario de Estudos Galegos, La Coruña, 2006.

González Clavijo, E., Dias da Silva, Í. F., Gutiérrez-Alonso, G., and Díez Montes, A.: U/Pb age of a large dacitic block locked in an Early Carboniferous synorogenic mélange in the Parautochthon of NW Iberia: New insights on the structure/sedimentation Variscan interplay, Tectonophysics, 681, 159-169, 2016, doi: 10.1016/j.tecto.2016.01.001

González Clavijo, E. and Martínez Catalán, J. R.: Stratigraphic record of preorogenic to synorogenic sedimentation, and tectonic evolution of imbricate thrusts in the Alcañices synform (northwestern Iberian Massif). In: Variscan Appalachian Dynamics: The building of the Late Palaeozoic Basement, Martínez Catalán, J. R., Hatcher Jr., R. D., Arenas, R., and Días García, F. (Eds.), Geological Society of America, Boulder, 2002.

Gutiérrez-Alonso, G., Fernández-Suárez, J., López-Carmona, A., and Gärtner, A.: Exhuming a cold case: The early granodiorites of the northwest Iberian Variscan belt—A Visean magmatic flare-up?, Lithosphere, doi: doi.org/10.1130/L706.1, 2018. 2018, doi: doi.org/10.1130/L706.1

Gutiérrez-Alonso, G., López-Carmona, A., Núñez-Guerrero, E., Martínez García, A., Fernández-Suárez, J., Pastor-Galán, D., Gutiérrez-Marco, J. C., Bernárdez, E., Colmenero, J. R., Hofmann, M., and Linnemann, U.: Neoproterozoic–paleozoic detrital sources in the Variscan foreland of northern Iberia: primary v. recycled sediments, Geological Society, London, Special Publications, 503, SP503-2020-2021, 2020, doi: 10.1144/sp503-2020-21

Gutiérrez-Marco, J. C., Piçarra, J. M., Meireles, C. A., Cózar, P., García-Bellido, D. C., Pereira, Z., Vaz, N., Pereira, S., Lopes, G., Oliveira, J. T., Quesada, C., Zamora, S., Esteve, J., Colmenar, J., Bernárdez, E., Coronado, I., Lorenzo, S., Sá, A. A., Dias da Silva, Í., González-Clavijo, E., Díez-Montes, A., and Gómez-Barreiro, J.: Early Ordovician–Devonian Passive Margin Stage in the Gondwanan Units of the Iberian Massif. In: The Geology of Iberia: A Geodynamic Approach: Volume 2: The Variscan Cycle, Quesada, C. and Oliveira, J. T. (Eds.), Springer International Publishing, Cham, 2019, doi: 10.1007/978-3-030-10519-8_3

Hajná, J., Žák, J., Ackerman, L., Svojtka, M., and Pašava, J.: A giant late Precambrian chert-bearing olistostrome discovered in the Bohemian Massif: A record of Ocean Plate Stratigraphy (OPS) disrupted by mass-wasting along an outer trench slope, Gondwana Research, 74, 173-188, 2019, doi: https://doi.org/10.1016/j.gr.2018.10.010

Iglesias, M., and Robardet, M.: Silúrico de Galicia Media- Central. Su importancia en la paleogeografía Varisca. Cuadernos Laboratorio Xeolóxico Laxe, 1, 99-115, 1980.

Jorge, R. C. G. S., Fernandes, P., Rodrigues, B., Pereira, Z., and Oliveira, J. T.: Geochemistry and provenance of the Carboniferous Baixo Alentejo Flysch Group, South Portuguese Zone, Sedimentary Geology, 284-285, 133-148, 2013, doi: https://doi.org/10.1016/j.sedgeo.2012.12.005

Krastel, S., Li, W., Urlaub, M., Georgiopoulou, A., Wynn, R. B., Schwenk, T., Stevenson, C., and Feldens, P.: Mass wasting along the NW African continental margin, Geological Society, London, Special Publications, 477, 151-167, 2019, doi: 10.1144/sp477.36

Kusky, T., Wang, J., Wang, L., Huang, B., Ning, W., Fu, D., Peng, H., Deng, H., Polat, A., Zhong, Y., and Shi, G.: Mélanges through time: Life cycle of the world's largest Archean mélange compared with Mesozoic and Paleozoic subduction-accretion-collision mélanges, Earth-Science Reviews, 209, 103303, 2020, doi: https://doi.org/10.1016/j.earscirev.2020.103303

Liang, X.-q. and Li, X.-h.: Late Permian to Middle Triassic sedimentary records in Shiwandashan Basin: Implication for the Indosinian Yunkai Orogenic Belt, South China, Sedimentary Geology, 177, 297-320, 2005, doi: https://doi.org/10.1016/j.sedgeo.2005.03.009

Linnemann, U., Gerdes, A., Hofmann, M., and Marko, L.: The Cadomian Orogen: Neoproterozoic to Early Cambrian crustal growth and orogenic zoning along the periphery of the West African Craton—Constraints from U–Pb zircon ages and Hf isotopes (Schwarzburg Antiform, Germany), Precambrian Research, 244, 236-278, 2014, doi: http://dx.doi.org/10.1016/j.precamres.2013.08.007

Linnemann, U., Ouzegane, K., Drareni, A., Hofmann, M., Becker, S., Gärtner, A., and Sagawe, A.: Sands of West Gondwana: An archive of secular magmatism and plate interactions: A case study from the Cambro-Ordovician section of the Tassili Ouan Ahaggar (Algerian Sahara) using U/Pb LA-ICP-MS detrital zircon ages, Lithos, 123, 188-203, 2012, doi: 10.1016/j.lithos.2011.01.010

López-Carmona, A., Abati, J., Pitra, P., and Lee, J. W.: Retrogressed lawsonite blueschists from the NW Iberian Massif: P–T–t constraints from thermodynamic modelling and 40Ar/39Ar geochronology, Contributions to Mineralogy and Petrology, 167, 1-20, 2014, doi: 10.1007/s00410-014-0987-5

López-Carmona, A., Abati, J., and Reche, J.: Petrologic modeling of chloritoid–glaucophane schists from the NW Iberian Massif, Gondwana Research, 17, 377-391, 2010, doi: https://doi.org/10.1016/j.gr.2009.10.003

López-Moro, F. J., Romer, R., López-Plaza, M., and Gónzalez Sánchez, M.: Zircon and allanite U-Pb ID-TIMS ages of vaugnerites from the Calzadilla pluton, Salamanca (Spain): dating mantle-derived magmatism and post-magmatic subsolidus overprint, Geologica acta, 15, 0395-0408, 2017, doi: 10.1344/GeologicaActa2017.15.4.9

Marcos, A. and Farias, P.: La estructura de la sutura varisca en la transversal de Cabo Ortegal (NW de España). In: Pires, C.C., Gomes, M.E.P., Coke, C. (eds.). Evoluçao geologica do Maciço Ibérico e seu enquadramento continental. 14 Reuniáo de Geologia do Oeste Peninsular, Vila Real, Portugal, Comunicações, 109-114, 1997.

Marcos, A., Farias, P., Galán, G., Fernández, F., and Llana-Fúnez, S.: Tectonic framework of the Cabo Ortegal Complex: A slab of lower crust exhumed in the Variscan orogen (northwestern Iberian Peninsula), Geologic Society of America - Special paper, 364, 143-162, 2002, doi: 10.1130/0-8137-2364-7.143

Marquínez García, J. L.: La geología del área esquistosa de Galicia Central (Cordillera Herciniana, NW de España), Instituto Geológico y Minero de España, Madrid, 1984.

Martínez Catalán, J. R., Arenas, R., Abati, J., Sánchez Martínez, S., Díaz García, F., Fernández-Suárez, J., González Cuadra, P., Castiñeiras, P., Gómez Barreiro, J., Díez Montes, A., González Clavijo, E., Rubio Pascual, F., Andonaegui, P., Jeffries, T. E., Alcock, J. E., Díez Fernández, R., and López Carmona, A.: A rootless suture and the loss of the roots of a mountain chain: The Variscan Belt of NW Iberia, C.R. Geoscience, 341, 114-126, 2009, doi: 10.1016/j.crte.2008.11.004

Martínez Catalán, J. R., Arenas, R., and Díez Balda, M. A.: Large extensional structures developed during the emplacement of a crystalline thrust sheet: the Mondoñedo nappe (NW Spain), Journal of Structural Geology, 25, 1815-1839, 2003, doi: 10.1016/S0191-8141(03)00038-5

Martínez Catalán, J. R., Arenas, R., Díaz García, F., and Abati, J.: Variscan accretionary complex of northwest Iberia: Terrane correlation and succession of tectonothermal events, Geology, 25, 1103-1106, 1997, doi: 10.1130/0091-7613(1997)025<1103:vaconi>2.3.co;2

Martínez Catalán, J. R., Arenas, R., Díaz García, F., González Cuadra, P., Gómez Barreiro, J., Abati, J., Castiñeiras, P., Fernández-Suárez, J., Sánchez Martínez, S., Andonaegui, P., González Clavijo, E., Díez Montes, A., Rubio Pascual, F., and Valle Aguado, B.: Space and time in the tectonic evolution of the northwestern Iberian Massif: Implications for the Variscan belt. In: 4-D Framework of Continental Crust, Hatcher Jr., R. D., Carlson, M. P., McBride, J. H., and Martínez Catalán, J. R. (Eds.), Geologic Society of America, Boulder, 2007, doi: 10.1130/2007.1200(21)

Martínez Catalán, J. R., Fernández-Suárez, J., Jenner, G. A., Belousova, E., and Díez Montes, A.: Provenance constraints from detrital zircon U-Pb ages in the NW Iberian Massif: implication for Palaeozoic plate configuration and Variscan evolution, Journal of the Geological Society, 161, 463-476, 2004, doi: 10.1144/0016-764903-054

Martínez Catalán, J. R., Fernández-Suárez, J., Meireles, C., González Clavijo, E., Belousova, E., and Saeed, A.: U-Pb detrital zircon ages in sinorogenic deposits of the NW Iberian Massif (Variscan belt): Interplay of Devonian-Carboniferous sedimentation and thrust tectonics, Journal of the Geological Society, 165, 687-698, 2008, doi: 10.1144/0016-76492007-066

Martínez Catalán, J. R., Gómez Barreiro, J., Dias da Silva, Í., Chichorro, M., López-Carmona, A., Castiñeiras, P., Abati, J., Andonaegui, P., Fernández-Suárez, J., González Cuadra, P., and Benítez-Pérez, J. M.: Variscan Suture Zone and Suspect Terranes in the NW Iberian Massif: Allochthonous Complexes of the Galicia-Trás os Montes Zone (NW Iberia). In: The Geology of Iberia: A Geodynamic Approach: Volume 2: The Variscan Cycle, Quesada, C. and Oliveira, J. T. (Eds.), Springer International Publishing, Cham, 2019, doi: 10.1007/978-3-030-10519-8_4

Martínez Catalán, J. R., González Clavijo, E., Meireles, C., Díez Fernández, R., and Bevis, J.: Relationships between syn-orogenic sedimentation and nappe emplacement in the hinterland of the Variscan belt in NW Iberia deduced from detrital zircons, Geological Magazine, 153, 38-60, 2016, doi: 10.1017/S001675681500028X

Martínez Catalán, J. R., Rubio Pascual, F. J., Montes, A. D., Fernández, R. D., Barreiro, J. G., Dias Da Silva, Í., Clavijo, E. G., Ayarza, P., and Alcock, J. E.: The late Variscan HT/LP metamorphic event in NW and Central Iberia: relationships to crustal thickening, extension, orocline development and crustal evolution, Geological Society, London, Special Publications, 405, 225-247, 2014, doi: 10.1144/sp405.1

Martínez García, E.: El Silúrico de San Vitero (Zamora). Comparación con las series vecinas e importancia orogénica. Act. Geol. Hisp. VII, 4, 104-108, 1972.

Matte, Ph.: La structure de la virgation hercynienne de Galice (Espagne). Revue de Géologie Alpine, 44, 1–128, 1968.

Meinhold, G., Morton, A. C., and Avigad, D.: New insights into peri-Gondwana paleogeography and the Gondwana super-fan system from detrital zircon U-Pb ages, Gondwana Research, 23, 661–665, 2013, doi: 10.1016/j.gr.2012.05.003

Meinhold, G., Morton, A. C., Fanning, C. M., Frei, D., Howard, J. D., Phillips, R. J., Strogen, D., and Whitham, A. G.: Evidence from detrital zircons for recycling of Mesoproterozoic and Neoproterozoic crust recorded in Paleozoic and Mesozoic sandstones of southern Libya, Earth and Planetary Science Letters, 312, 164–175, 2011, doi: doi: 10.1016/j.epsl.2011.09.056

Meireles, C.: Litoestratigrafia do Paleozoico do Sector a Nordeste de Bragança (Trás-os-Montes), Instituto Universitario de Geología "Isidro Parga Pondal" - Área de Xeoloxía e Minería do Seminario de Estudos Galegos, Coruña, 2013.

Meireles, C. A., Santos, J., Pereira, E., and Ribeiro, A.: Carta Geológica de Portugal à escala 1:50.000, Folha 3-D (Espinhosela), Instituto Geológico e Mineiro, 1999a.

Meireles, C. A., Santos, J., Pereira, E., and Ribeiro, A.: Carta Geológica de Portugal à escala 1:50.000, Folha 4-C (Deilão), Instituto Geológico e Mineiro, 1999b.

Meireles, C., Sá, A., Piçarra, J. M., González Clavijo, E., and Ribeiro, A.: Novos avanços no conhecimento do limite Ordovícico-Silúrico na região de Trás-os-Montes (NE Portugal), Estremoz, 2006, 645-648.

Mulder, J. A., Karlstrom, K. E., Fletcher, K., Heizler, M. T., Timmons, J. M., Crossey, L. J., Gehrels, G. E., and Pecha, M.: The syn-orogenic sedimentary record of the Grenville Orogeny in southwest Laurentia, Precambrian Research, 294, 33-52, 2017, doi: https://doi.org/10.1016/j.precamres.2017.03.006

Munhá, J., Ribeiro, A., and Ribeiro, M. L.: Blueschists in the Iberian Variscan Chain (Trás-os-Montes, NE Portugal), Comunicações dos Serviços Geológicos de Portugal, 70, 31-53, 1984.

Murphy, J. B., Gutiérrez-Alonso, G., Fernández-Suárez, J., and Braid, J. A.: Probing crustal and mantle lithosphere origin through Ordovician volcanic rocks along the Iberian passive margin of Gondwana, Tectonophysics, 461, 166-180, 2008, doi: https://doi.org/10.1016/j.tecto.2008.03.013

Noronha, F., Ribeiro, M. A., Martins, H., and Lima, J.: Carta Geológica de Portugal à escala 1:50.000, Folha 6-D (Vila Pouca de Aguiar), Laboratório Nacional de Energia e Geologia, 1998.

Nuño Ortea, C., López García, M.J., Ferragne, A., and Rúiz García, C.: Mapa Geológico de España, E. 1:50.000 y Memoria, Hoja 303-Verín, Segunda Serie, IGME, Madrid, 29 p, 1981.

Ogata, K., Festa, A., Pini, G. A., and Alonso, J. L.: Submarine Landslide Deposits in Orogenic Belts, Submarine Landslides, doi: 10.1002/9781119500513.ch1, 2019. 1-26, 2019, doi: 10.1002/9781119500513.ch1

Oliveira, J. T., González-Clavijo, E., Alonso, J., Armendáriz, M., Bahamonde, J. R., Braid, J. A., Colmenero, J. R., Dias da Silva, Í., Fernandes, P., Fernández, L. P., Gabaldón, V., Jorge, R. S., Machado, G., Marcos, A., Merino-Tomé, Ó., Moreira, N., Murphy, J. B., Pinto de Jesus, A., Quesada, C., Rodrigues, B., Rosales, I., Sanz-López, J., Suárez, A., Villa, E., Piçarra, J.

M., and Pereira, Z.: Synorogenic Basins. In: The Geology of Iberia: A Geodynamic Approach: Volume 2: The Variscan Cycle, Quesada, C. and Oliveira, J. T. (Eds.), Springer International Publishing, Cham, 2019a, doi: 10.1007/978-3-030-10519-8_11

Oliveira, J. T., Quesada, C., Pereira, Z., Matos, J. X., Solá, A. R., Rosa, D., Albardeiro, L., Díez-Montes, A., Morais, I., Inverno, C., Rosa, C., and Relvas, J.: South Portuguese Terrane: A Continental Affinity Exotic Unit. In: The Geology of Iberia: A Geodynamic Approach: Volume 2: The Variscan Cycle, Quesada, C. and Oliveira, J. T. (Eds.), Springer International Publishing, Cham, 2019b, doi: 10.1007/978-3-030-10519-8_6

Pereira, E., Ferreira da Silva, A., Rebelo, J. A., Ribeiro, A., and Dias, R.: Carta Geológica de Portugal à escala 1:50.000, Folha 11-D (Carviçais), Laboratório Nacional de Energía e Geologia, Lisboa, 2009.

Pereira, E., Pereira, D. Í., Rodrigues, J. F., Ribeiro, A., Noronha, F., Ferreira, N., Sá, C. M. d., Farinha Ramos, J., Moreira, A., and Oliveira, A. F.: Notícia Explicativa da Folha 2 da Carta Geológica de Portugal à Escala 1:200.000, Instituto Nacional de Engenharia, Tecnologia e Inovação, Lisboa, 2006.

Pereira, E., Ribeiro, A., and Castro, P.: Notícia Explicativa da Carta Geológica de Portugal à Escala 1:50.000 - Folha 7-D (Macedo de Cavaleiros) Laboratório Nacional de Energía e Geologia, Lisboa, 2000.

Pereira, E., Ribeiro, A., Rebelo, J. A., and Castro, P.: Notícia Explicativa da Carta Geológica de Portugal à Escala 1:50.000 - Folha 11-B (Mogadouro) Laboratório Nacional de Energía e Geologia, Lisboa, 2008.

Pereira, E.: Estudo geológico-estructural da região de Celorico de Basto e sua intrepretação geodinâmica, PhD, Universidade de Lisboa, Lisboa, 274 pp., 1987.

Pereira, M. F., Chichorro, M., Johnston, S. T., Gutiérrez-Alonso, G., Silva, J. B., Linnemann, U., Hofmann, M., and Drost, K.: The missing Rheic Ocean magmatic arcs: Provenance analysis of Late Paleozoic sedimentary clastic rocks of SW Iberia, Gondwana Research, 22, 882-891, 2012, doi: 10.1016/j.gr.2012.03.010

Pereira, M. F., Gama, C., Dias da Silva, Í., Fuenlabrada, J. M., Silva, J. B., and Medina, J.: Isotope geochemistry evidence for Laurussian-type sources of South Portuguese Zone Carboniferous turbidites (Variscan Orogeny), Geological Society, London, Special Publications, 503, SP503-2019-2163, 2020a, doi: 10.1144/sp503-2019-163

Pereira, M. F., Gama, C., Dias da Silva, Í., Silva, J. B., Hofmann, M., Linnemann, U., and Gärtner, A.: Chronostratigraphic framework and provenance of the Ossa-Morena Zone Carboniferous basins (southwest Iberia), Solid Earth, 11, 1291-1312, 2020b, doi: 10.5194/se-11-1291-2020

Pereira, Z., Meireles, C., and Pereira, E.: Upper Devonian palynomorphs of NE sector of Trás-os-Montes (Central Iberian Zone), Badajoz, 1999, 201-206.

Pérez-Cáceres, I., Martínez Poyatos, D., Simancas, J. F., and Azor, A.: Testing the Avalonian affinity of the South Portuguese Zone and the Neoproterozoic evolution of SW Iberia through detrital zircon populations, Gondwana Research, 42, 177-192, 2017, doi: https://doi.org/10.1016/j.gr.2016.10.010

Pérez-Estaún, A.: Aportaciones al conocimiento del Carbonífero de San Clodio (Prov. de Lugo), Brev. Geol. Ast., año XVIII, No. 1, pp. 3-5, 1974.

Piçarra, J. M., Gutiérrez Marco, J. C., Sá, A. A., Meireles, C., and González Clavijo, E.: Silurian graptolite biostratigraphy of the Galicia-Trás-os-Montes Zone (Spain and Portugal), Journal of the Geological Society of Sweden, 128, 185-188, 2006b.

Piçarra, J., Gutiérrez-Marco, J., Sarmiento, G. N., and Sá, A.: Novos dados de Conodontes e Graptólitos no Paleozóico parautóctone da Zona Galiza–Trás-os-Montes (Espanha e Portugal), 2006a, 653-656.

Piçarra, J. M. and Meireles, C.: Identificação de graptólitos do Ludlow (Silúrico superior), na área de Guadramil (Bragança, Zona Centro Ibérica, Portugal): implicações na estratigrafia regional, Ciências da Terra (UNL), nº esp. V, A126-A129, 2003.

Pin, C., Paquette, J. L., Ábalos, B., Santos, F. J., and Gil Ibarguchi, J. I.: Composite origin of an early Variscan transported suture: Ophiolitic units of the Morais Nappe Complex (north Portugal), Tectonics, 25, TC5001, 2006, doi: 10.1029/2006tc001971

Puetz, S. J.: A relational database of global U–Pb ages, Geoscience Frontiers, 9, 877-891, 2018, doi: https://doi.org/10.1016/j.gsf.2017.12.004

Ribeiro, A.: Contribution à l'étude téctonique de Trás-os-Montes Oriental, Serviços Geológicos de Portugal, Lisboa, 1974.

Ribeiro, A., Pereira, E., Dias, R., Gil Ibarguchi, J. I., and Arenas, R.: Allochthonous Sequences. In: Pre-Mesozoic Geology of Iberia, Dallmeyer, R. D. and Garcia, E. M. (Eds.), Springer Berlin Heidelberg, Berlin, Heidelberg, 1990, doi: 10.1007/978-3-642-83980-1_15

Ribeiro, M. L.: Estudo litogeoquímico das formações metassedimentares encaixantes de mineralizações em Trás-os-Montes Ocidental. Implicações metalogenéticas. Tese de Doutoramentos, Univ. Porto, 231pp, 1998.

Ribeiro, M. A., Noronha, F., and Cuney, M.: Lithogeochemical study of the metassedimentary units of Vila Pouca de Aguiar Área (Westhern Trás-os-Montes, Northern Portugal). Univ. Porto. Mem. Mus. Lab. Mineral. Geol. Fac. Ciênc. Univ. Porto, Mem. 3: 299-303, 1993.

Ribeiro, M. L. and Ribeiro, A.: Analise petrográfica e textural dos Gneisses de Saldanha (Trás-os-Montes oriental): elementos para nova intrepretação estratigráfica, Comunicações do Instituto Geológico e Mineiro, 91, 5-16, 2004.

Ribeiro, M. L. and Ribeiro, A.: Signification paléógéographique et tectonique de la présence de galets de roches métamorphiques dans le flysch d'âge dévonien supérieur du Tras-Os-Montes oriental (Nord-Est du Portugal), C.R. Acad. Sc. Paris, 278, 1974.

Riemer, W.: Datos para el conocimiento de la estratigrafía de Galicia, Notas y Comunicaciones. IGME, 81, 7-20, 1966, doi:

Rodrigues, J. F.: Estructuras do Arco de Santa Comba-Serra da Garraia. Parautoctone de Trás-os-Montes, Tese de Doutoramento, Departamento de Geologia, Universidade de Lisboa - Faculdade de Ciências, Lisboa, 308 pp., 2008.

Rodrigues, J. F., Pereira, E., and Ribeiro, A.: Estructura Interna do Complexo de Mantos Parautoctones, Sector de Murça-Mirandela (NE de Portugal). In: Geologia de Portugal no Contexto da Ibéria, Dias, R., Araújo, A., Terrinha, P., and Kullberg, J. C. (Eds.), Universidade de Évora, Évora, 2006.

Rodrigues, J. F., Ribeiro, A., and Pereira, E.: Complexo de Mantos Parautóctones do NE de Portugal:estructura interna e tectonoestratigrafia. In: Geologia de Portugal, Dias, R., Araújo, A., Terrinha, P., and Kullberg, J. C. (Eds.), Escolar Editora, Lisboa, 2013.

Rodrigues, J. F., Ribeiro, A., Pereira, E., Ribeiro, M. L., Ferreira, N., and Meireles, C. A.: Carta Geológica de Portugal à escala 1:50.000, Folha 7-C (Mirandela), Laboratório Nacional de Energia e Geologia, 2010.

Rodrigues, J., Pereira, E., Ribeiro, A., and Meireles, C.: Organização tectonoestratigráfica do Complexo Parautóctone do NE de Portugal: uma proposta. VI Congr. Nal. Geol. Lisboa. Actas D76-D78; Ciências da Terra (UNL). Esp. V, 2003.

Rodríguez, J., Cosca, M. A., Gil Ibarguchi, J. I., and Dallmeyer, R. D.: Strain partitioning and preservation of 40Ar/39Ar ages during Variscan exhumation of a subducted crust (Malpica–Tui complex, NW Spain), Lithos, 70, 111-139, 2003, doi: 10.1016/S0024-4937(03)00095-1

Romariz, C.: Graptolitos silúricos do Noroeste Peninsular. Comun. Serv. Geol. Port. 53, 107–155, 1969.

Rubio Pascual, F., Arenas, R., García, F. D. a., Martínez Catalán, J. R., Abati, J., Catalán, J. R. M., Hatcher, R. D., Jr., Arenas, R., and García, F. D.: Contrasting high-pressure metabasites from the Santiago unit (Ordenes Complex, northwestern Iberian Massif, Spain). In: Variscan-Appalachian dynamics: The building of the late Paleozoic basement, Geological Society of America, 2002, doi: 10.1130/0-8137-2364-7.105

Sá, A.A., Meireles, C., Castro, P., and Vaz, N.: Ordovician “olistoliths” from Casal do Rato Formation (Trás-os-Montes): contribution to their reappraisal. Comun. Inst. Geol. Min. 101 (ESPECIAL 1), 307–311, 2014.

Sánchez-García, T., Chichorro, M., Solá, A. R., Álvaro, J. J., Díez-Montes, A., Bellido, F., Ribeiro, M. L., Quesada, C., Lopes, J. C., Dias da Silva, Í., González-Clavijo, E., Gómez Barreiro, J., and López-Carmona, A.: The Cambrian-Early Ordovician Rift Stage in the Gondwanan Units of the Iberian Massif. In: The Geology of Iberia: A Geodynamic Approach: Volume 2: The Variscan Cycle, Quesada, C. and Oliveira, J. T. (Eds.), Springer International Publishing, Cham, 2019, doi: 10.1007/978-3-030-10519-8_2

Santos Zalduegui, J. F., Schärer, U., and Gil Ibarguchi, J. I.: Isotope constraints on the age and origin of magmatism and metamorphism in the Malpica-Tuy allochthon, Galicia, NW Spain, Chemical Geology, 121, 91-103, 1995, doi: 10.1016/0009-2541(94)00123-P

Santos Zalduegui, J. F., Schärer, U., Gil Ibarguchi, J. I., and Girardeau, J.: Origin and evolution of the Paleozoic Cabo Ortegal ultramafic-mafic complex (NW Spain): U-Pb, Rb-Sr and Pb-Pb isotope data, Chemical Geology, 129, 281-304, 1996, doi: 10.1016/0009-2541(95)00144-1

Sarmiento, G. N., and García-López, S.: El Índice de Alteración de Color (CAI) de los conodontos: limitaciones y posibilidades. Ejemplos de su aplpicación en el Hercínico Ibérico. Rev. Soc. Geol. España, 9 (1-2). 113-123, 1996.

Sarmiento, G. N., Calvo, A. A., and González Clavijo, E.: Conodontos paleozoicos (Ashgill-Emsiense) del Sinforme de Alcañices (oeste de Zamora, España), Grandal d’Anglade, A., Gutiérrez-Marco, JC and Santos Fidalgo, L.(eds)., Libro de Resúmenes y Excursiones, XIII Jornadas de Paleontología and V Reunión Internacional Proyecto, 351, 108-111, 1997

Sarmiento, G. N., Piçarra, J. M., Rebelo, J. A., Robardet, M., Gutiérrez Marco, J. C., Storch, P., and Rábano, I.: Le Silurien du Synclinorium de Moncorvo (NE du Portugal): Biostratigraphie et importance paléogéographique, GEOBIOS, 32, 749-767, 1998, doi: 10.1016/S0016-6995(99)80062-X

Schermerhorn, L. J. G. and Kotsch, S.: First occurrence of lawsonite in Portugal and tectonic implications, Comunicações do Instituto Geológico e Mineiro, 70, 23-29, 1984

Smeraglia, L., Aldega, L., Billi, A., Carminati, E., Di Fiore, F., Gerdes, A., Albert, R., Rossetti, F., and Vignaroli, G.: Development of an Intrawedge Tectonic Mélange by Out-of-Sequence Thrusting, Buttressing, and Intraformational Rheological Contrast, Mt. Massico Ridge, Apennines, Italy, Tectonics, 38, 1223-1249, 2019, doi: 10.1029/2018tc005243

Sousa, M. B.: Considerações sobre a estratigrafia do Complexo Xisto-Grauváquico (CXG) e sua relação com o Paleozóico Inferior, Cuadernos Geología Ibérica, 9, 9-36, 1984.

Stampfli, G. M., Hochard, C., Vérard, C., Wilhem, C., and vonRaumer, J.: The formation of Pangea, Tectonophysics, 593, 1-19, 2013, doi: 10.1016/j.tecto.2013.02.037

Stephan, T., Kroner, U. W. E., and Romer, R. L.: The pre-orogenic detrital zircon record of the Peri-Gondwanan crust, Geological Magazine, doi: 10.1017/S0016756818000031, 2018. 1-27, 2018, doi: 10.1017/S0016756818000031

Teixeira, C., and Pais, J.: Sobre a presença de Devónico na região de Bragança (Guadramil e Mofreita) e de Alcañices (Zamora). Bol. Soc. Geol. Portugal, 18, 199–202, 1973.

Vacas, J. M. and Martínez Catalán, J. R.: El sinforme de Alcañices en la transversal de Manzanal del Barco, Stvdia Geológica Salmantina, 24, 151-175, 1987

Valladares, M. I., Barba, P., Ugidos, J. M., Colmenero, J. R., and Armenteros, I.: Upper Neoproterozoic–Lower Cambrian sedimentary successions in the Central Iberian Zone (Spain): sequence stratigraphy, petrology and chemostratigraphy. Implications for other European zones, International Journal of Earth Sciences, 89, 2-20, 2000, doi: 10.1007/s005310050314

Valverde-Vaquero, P., Farias, P., Marcos, A., and Gallastegui, G.: U-Pb dating of Siluro-Ordovician volcanism in the Verín Synform (Ourense; Schistose Domain, Galicia-Trás-os-Montes Zone), Geogaceta, 41, 247-250, 2007

Valverde-Vaquero, P., Marcos, A., Farias, P., and Gallastegui, G.: U-Pb dating of Ordovician felsic vulcanics in the Schistose Domain of the Galicia-Trás-os-Montes Zone near Cabo Ortegal (NW Spain), Geologica Acta, 3, 27-37, 2005, doi: 10.1344/105.000001412

Vermeesch, P.: IsoplotR: A free and open toolbox for geochronology, Geoscience Frontiers, 9, 1479-1493, 2018, doi: https://doi.org/10.1016/j.gsf.2018.04.001

Wilmsen, M., Fürsich, F. T., Seyed-Emami, K., Majidifard, M. R., and Taheri, J.: The Cimmerian Orogeny in northern Iran: tectono-stratigraphic evidence from the foreland, Terra Nova, 21, 211-218, 2009, doi: 10.1111/j.1365-3121.2009.00876

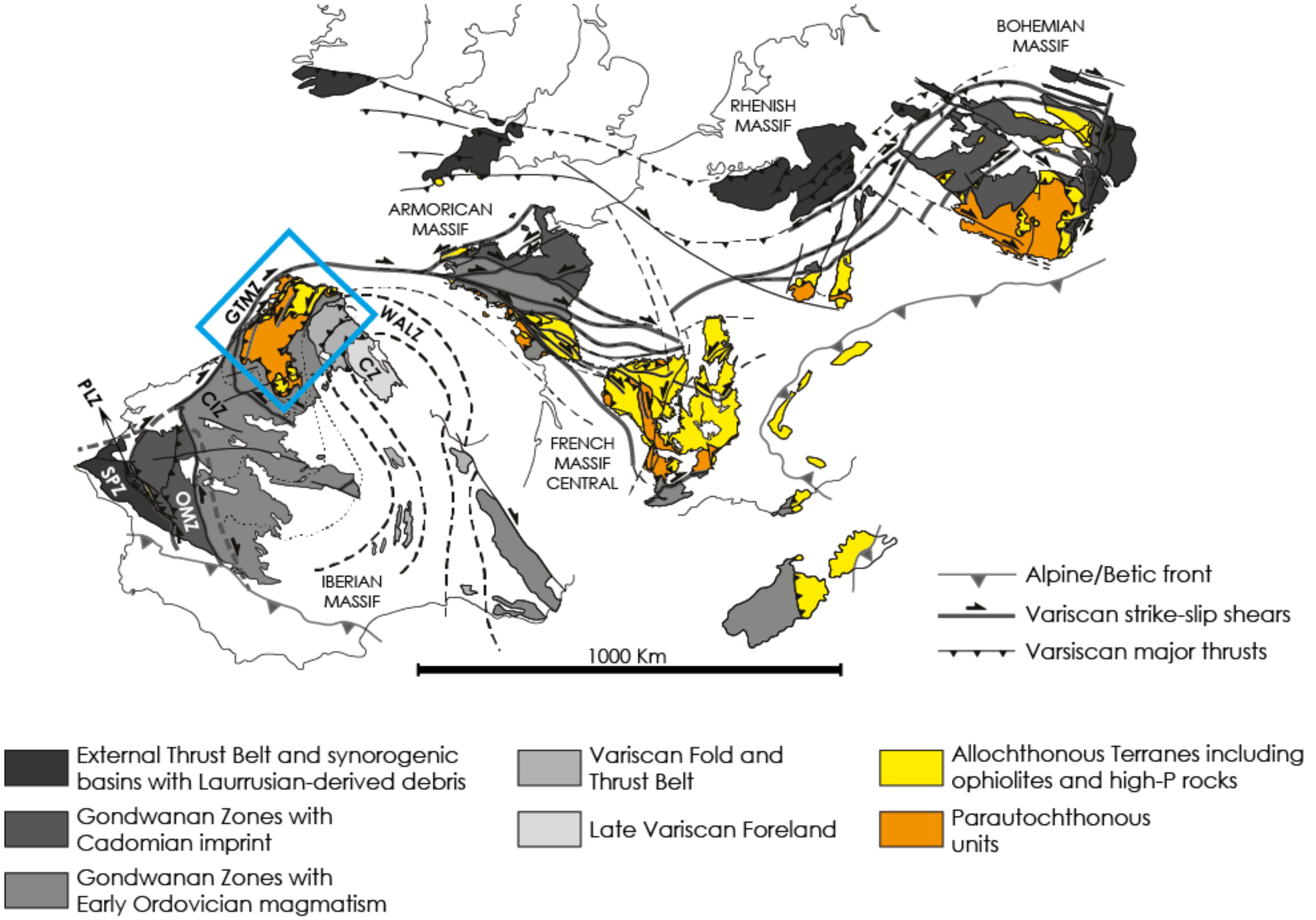

**Figure 1: Map of the European Variscan belt at the end of the Carboniferous. Modified from Martínez Catalán et al. (2007). Acronyms: CZ - Cantabrian Zone; WALZ - West Asturian-Leonese Zone; GTMZ - Galicia - Trás-os-Montes Zone; CIZ - Central Iberian Zone; OMZ - Ossa-Morena Zone; PLZ - Pulo do Lobo Zone; SPZ - South Portuguese Zone. Blue rectangle area is represented in Fig. 2.**

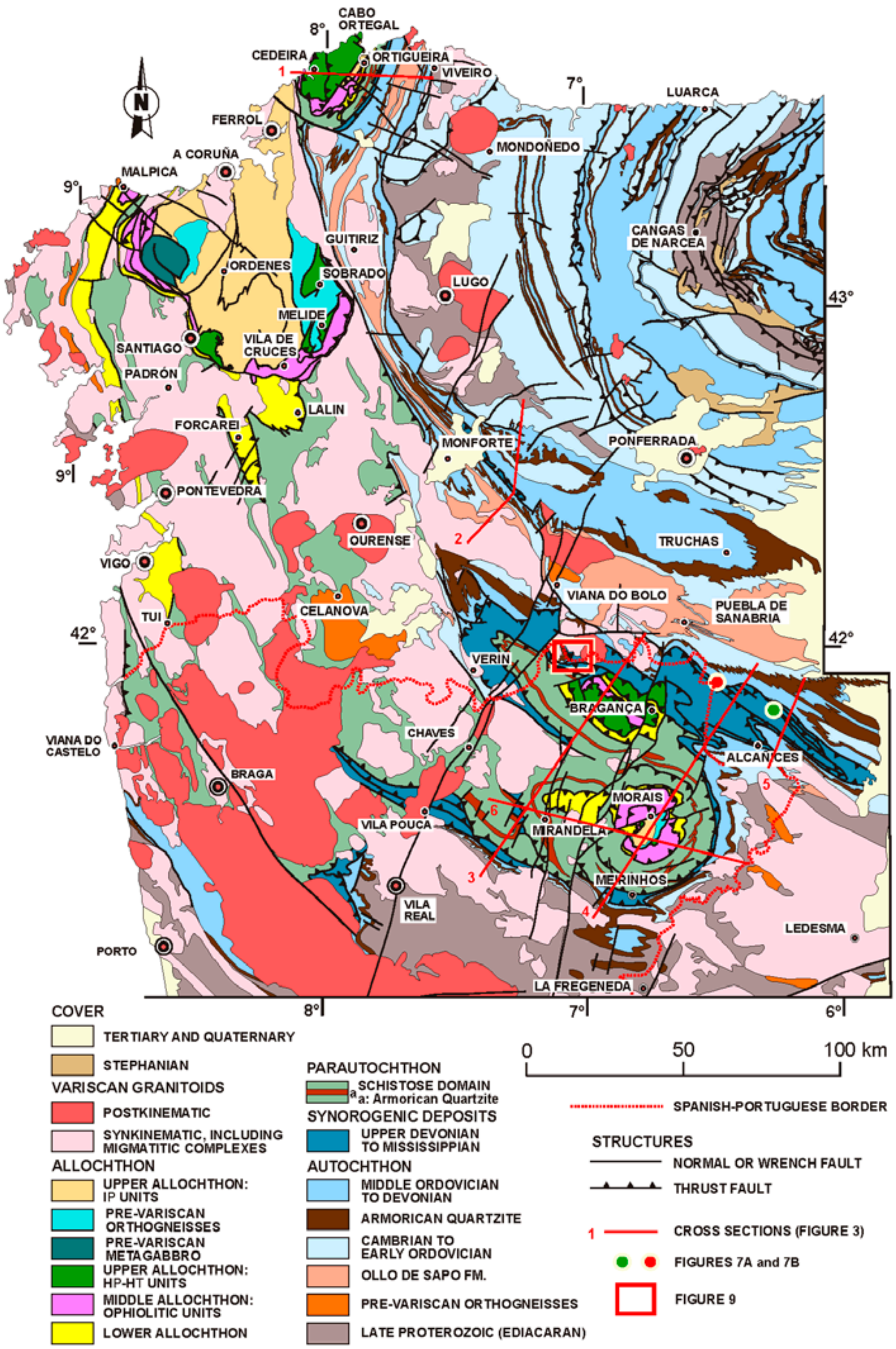

**Figure 2: Simplified geological map of the NW Iberia Variscan Massif modified from Martínez Catalán et al. (1997). The limits between Lower Allochthon, Upper and Lower Parautochthon and the autochthonous unit have been modified according this work.**

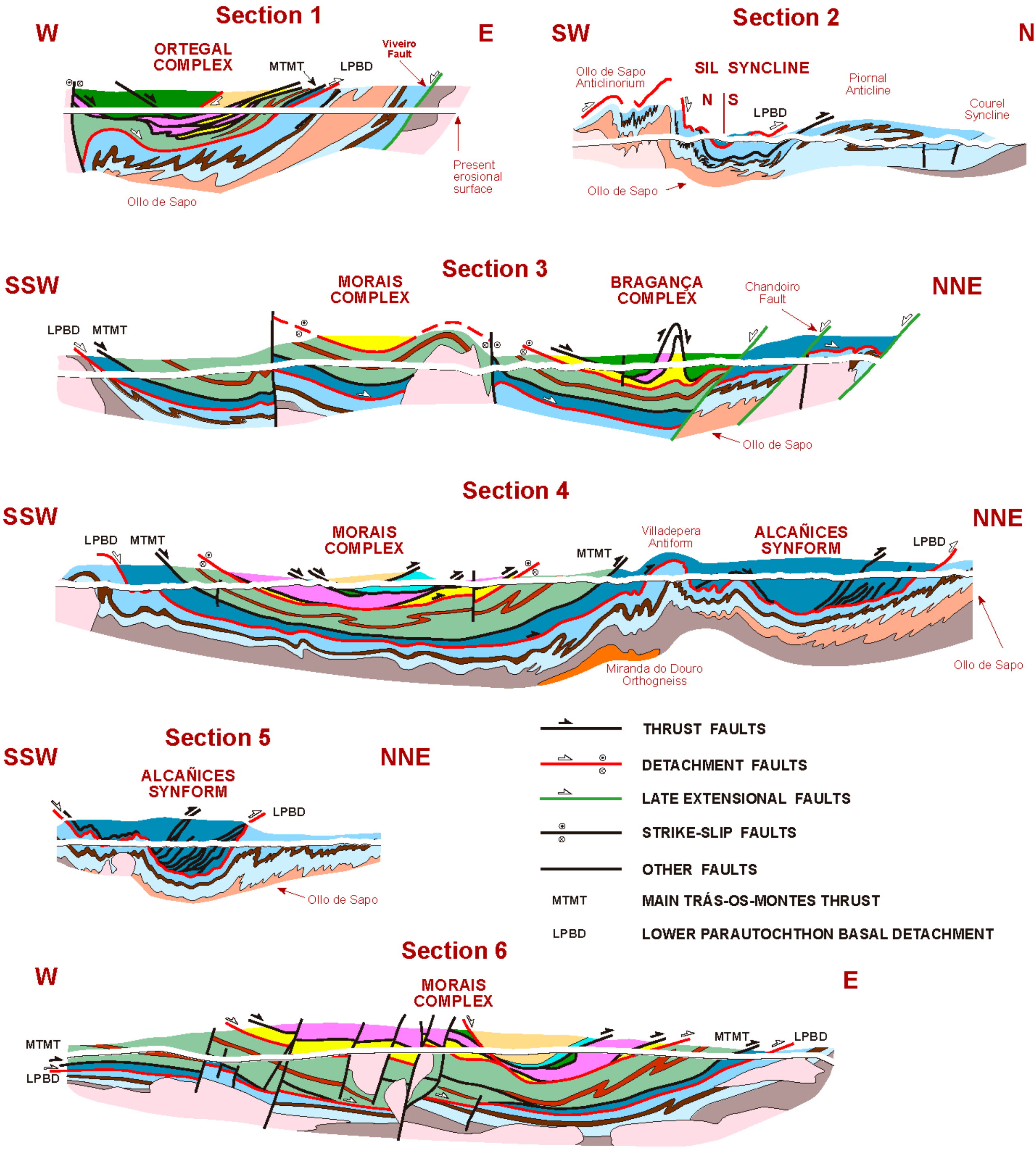

**Figure 3: Representative cross sections of the Variscan syn-orogenic tectonic carpet. See Fig. 2 for location.**

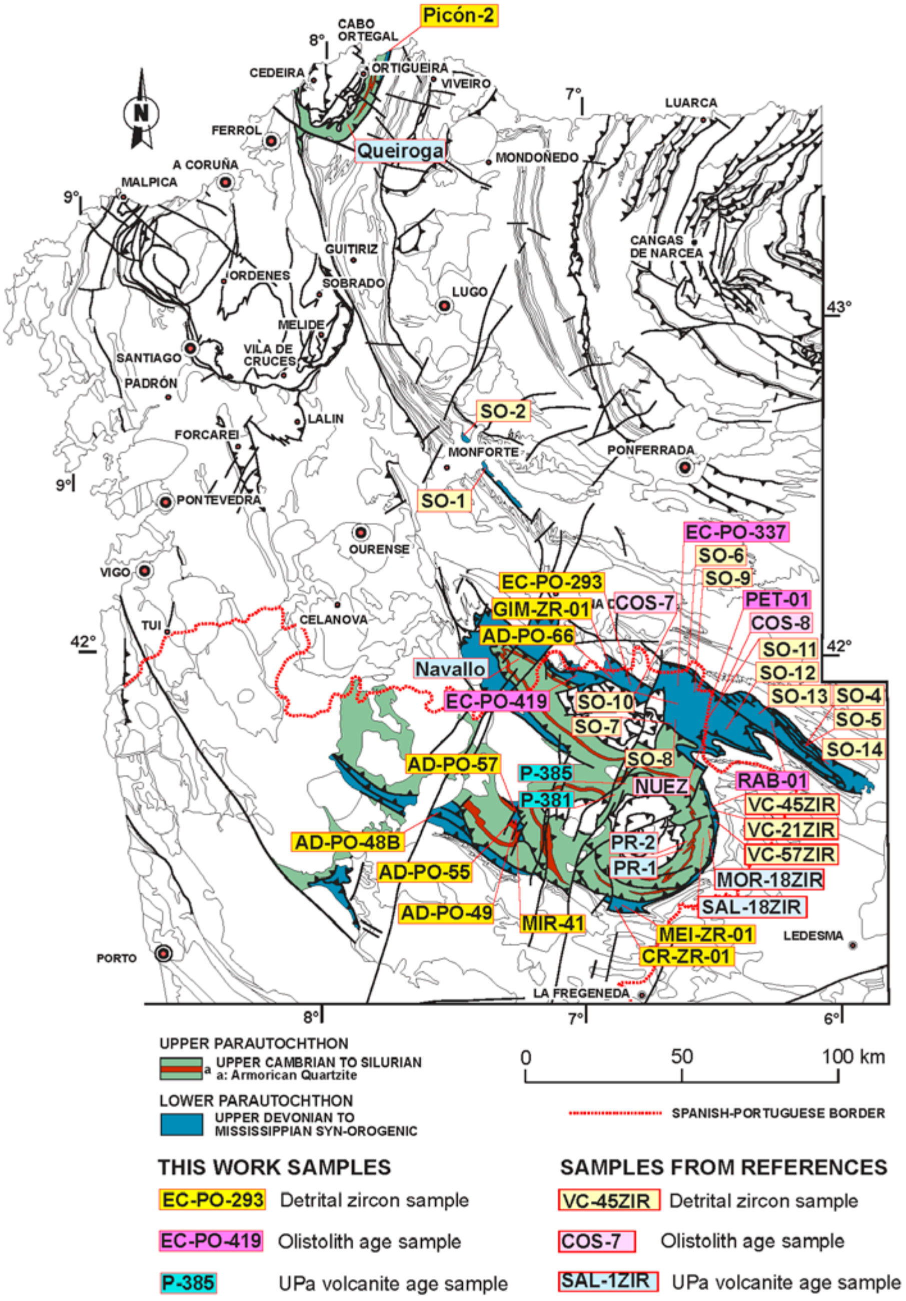

**Figure 5: Situation map of the samples studied and referred in this work.**

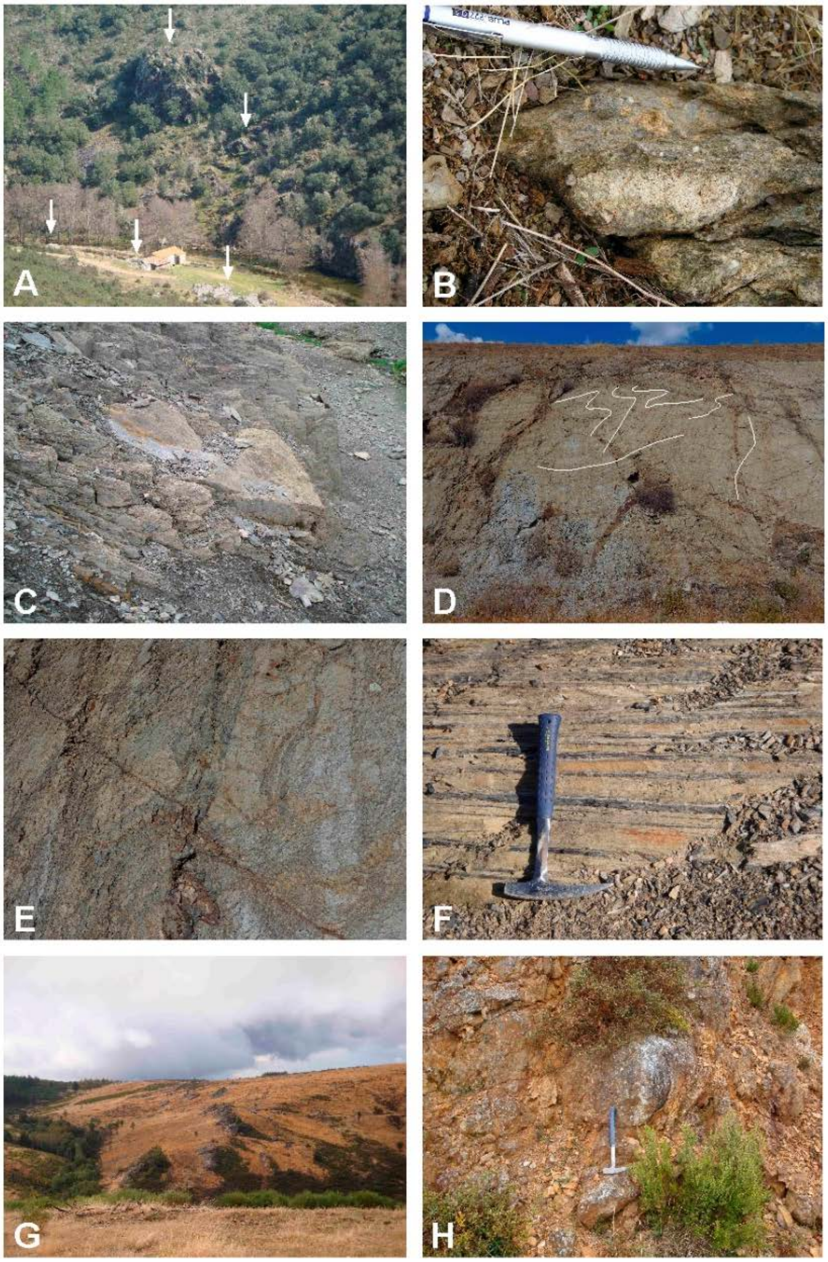

**Figure 5: Field aspects of the synorogenic sediments of the LPa: A) Lower Ordovician white quartzite olistoliths (arrows) in Rábano Fm; B)Centimetre size foliated rhyolite in an Almendra Fm micronglomerate; C) Metric glided block of limestone in an Almendra Fm grey phyllite bed; D) Slump folds in flyschoid facies at the Meirinhos syn-orogenic LPa; 2) Broken beds in a flyschoid facies of the Meirnhos Fm; F) Centimetre thick flysch facies in the LPa unit exposed in the tectonic window western Mirandela; G) Quartzite, lydite and rhyolitic tuff olistoliths in the LPa northern Bragança Complex; H) Blocks of quartzite (under the hammer) and lydite (above) in the LPa northern Bragança Complex**

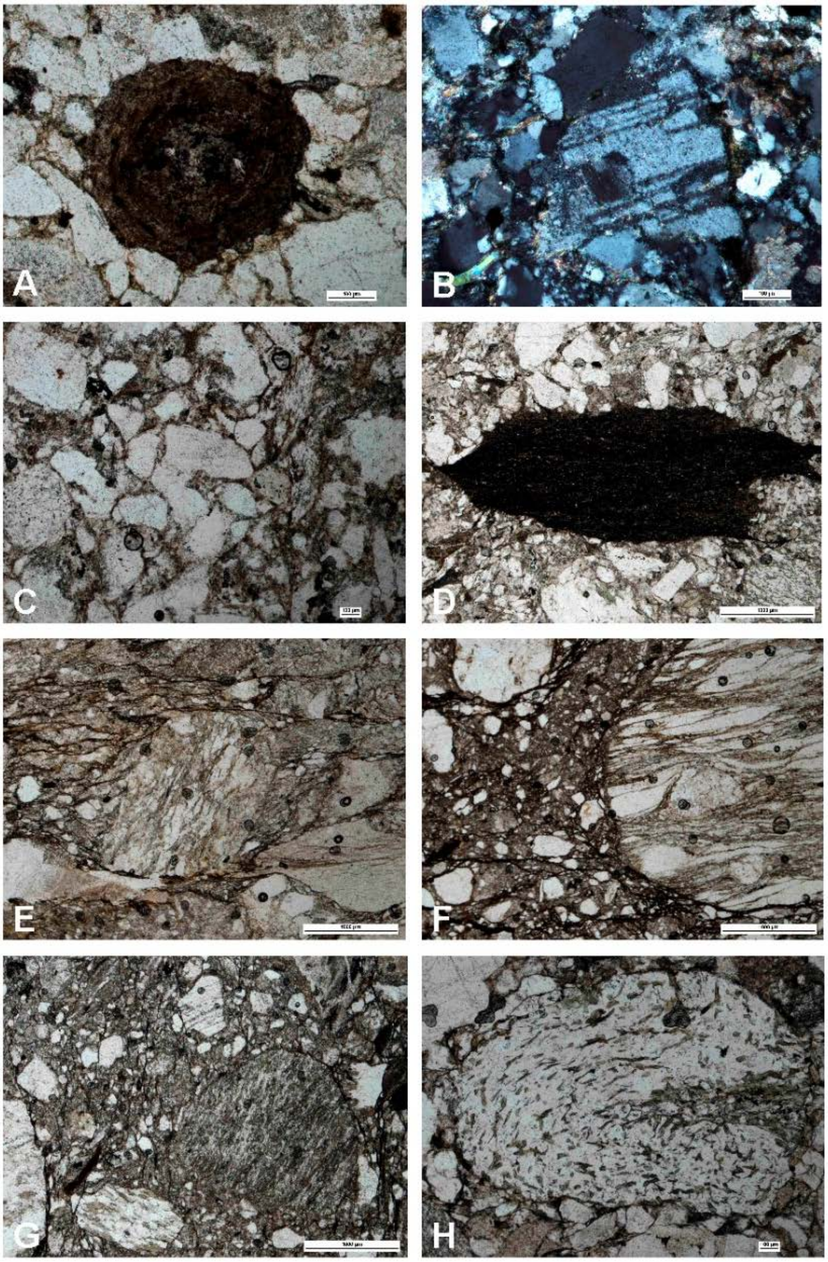

**Figure 6: Microphotographs of the sedimentary textures in the LPa formations, surrounding clasts of different natures. A) Bioclast in a Rábano Fm quartzlitharenite; B) Plagioclase mineraloclast in a Rábano Fm quartzlitharenite; C) Broken up volcanic quartz crystals in a Rábano Fm quartzlitharenite; D) Lithoclast made of black phyllite in a San Vitero Fm litharenite; E) Rounded clast displaying tectonic foliation almost normal to the sourronding external $C_1$ foliation (San Vitero Fm); F) Partial view of a rounded clast displaying mylonitic banding in an Almendra Fm microconglomerate; G) Randomly oriented clasts bearing previous foliation in an Almendra Fm microconglomerate; H) Rounded foliated clast displaying a microfold in an Almendra Fm microconglomerate.**

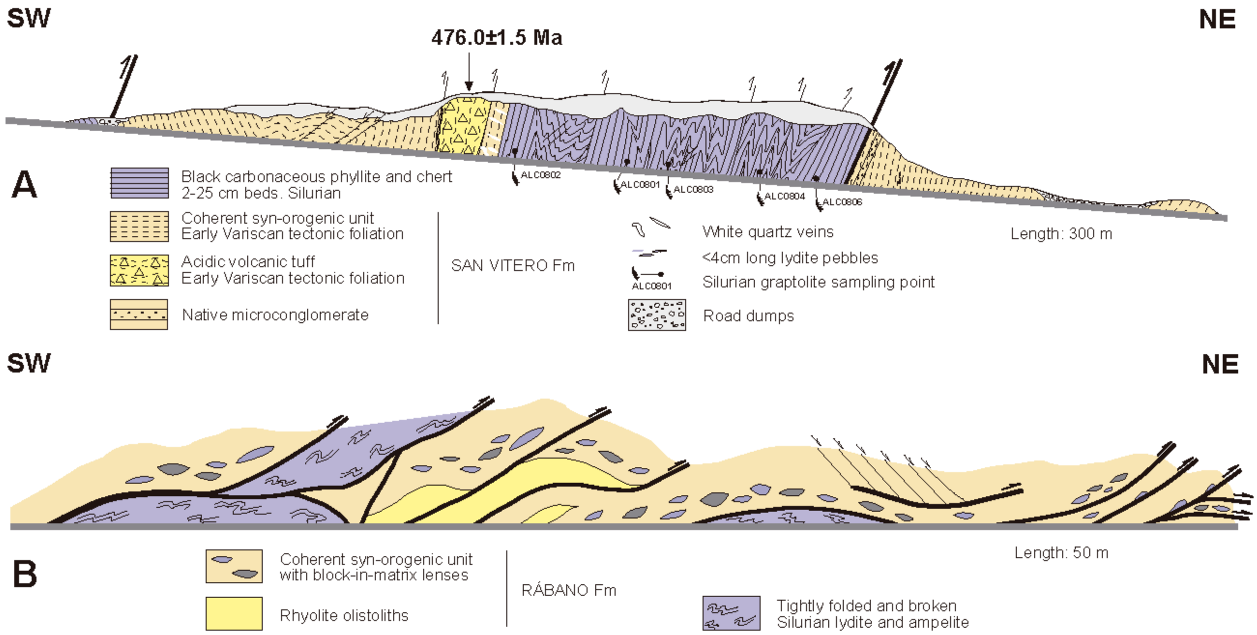

**Figure 7: Examples of tectonic mélanges at the base of the syn-orogenic units in the Alcañices synform. A: San Vitero duplex slices showing a Lower Ordovician volcanic olistolith above the Silurian fossiliferous sequence. B: Rábano Fm with rhyolite olistoliths of unknown age and displaying sedimentary block-in-matrix facies lately incorporated to a tectonic mélange.**

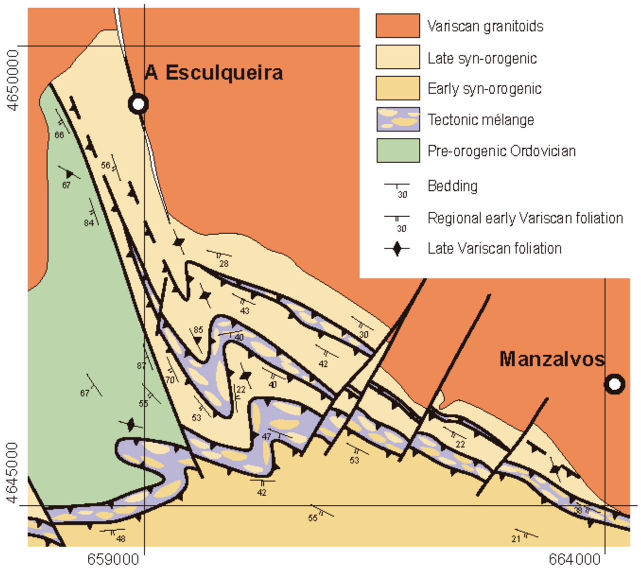

**Figure 8: Geological sketch of one area N of the Bragança Complex showing slices of syn-orogenic units bounded by tectonics mélanges involving the syn-orogenic and the black Silurian rocks. The multiplex was openly folded during the Late Variscan event (C$_3$). Coordinates system: UTM-WGS84.**

**Figure 9: Field aspects of the block in matrix formations and olistoliths in the LPa. A) Rhyolite block in the LPa northern Bragança**
1095 **Complex inside a quartzlitharenite; B) Flyschoid sequence in the Verín synform SW limb; C) Thrust band involving black Silurian ampelite, and rhyolite (whitish) and lydite (black) blocks in the NE limb of the Verín synform; D) Thrust band deforming rhyolite (yellowish and whitish), quartzlitharenite (brown in the right side) and ampelite (black) at the NE limb of the Verín synform; 3) Black Silurian condensed facies in a tectonic slice inside a tectonic mélange at the NE limb of the Verín synform; F) Flyschoid sequence with sedimentary and load structures in the LPa at the easternmost part of the Verín synform SW limb; G) Olistolith made**
1100 **of UPa rocks displaying the characteristic arrangement of tectonic foliations in the LPa of the easternmost part of the Verín synform SW limb; H) Tectonic foliation array of the UPa lower part at the SW of the Morais Complex.**

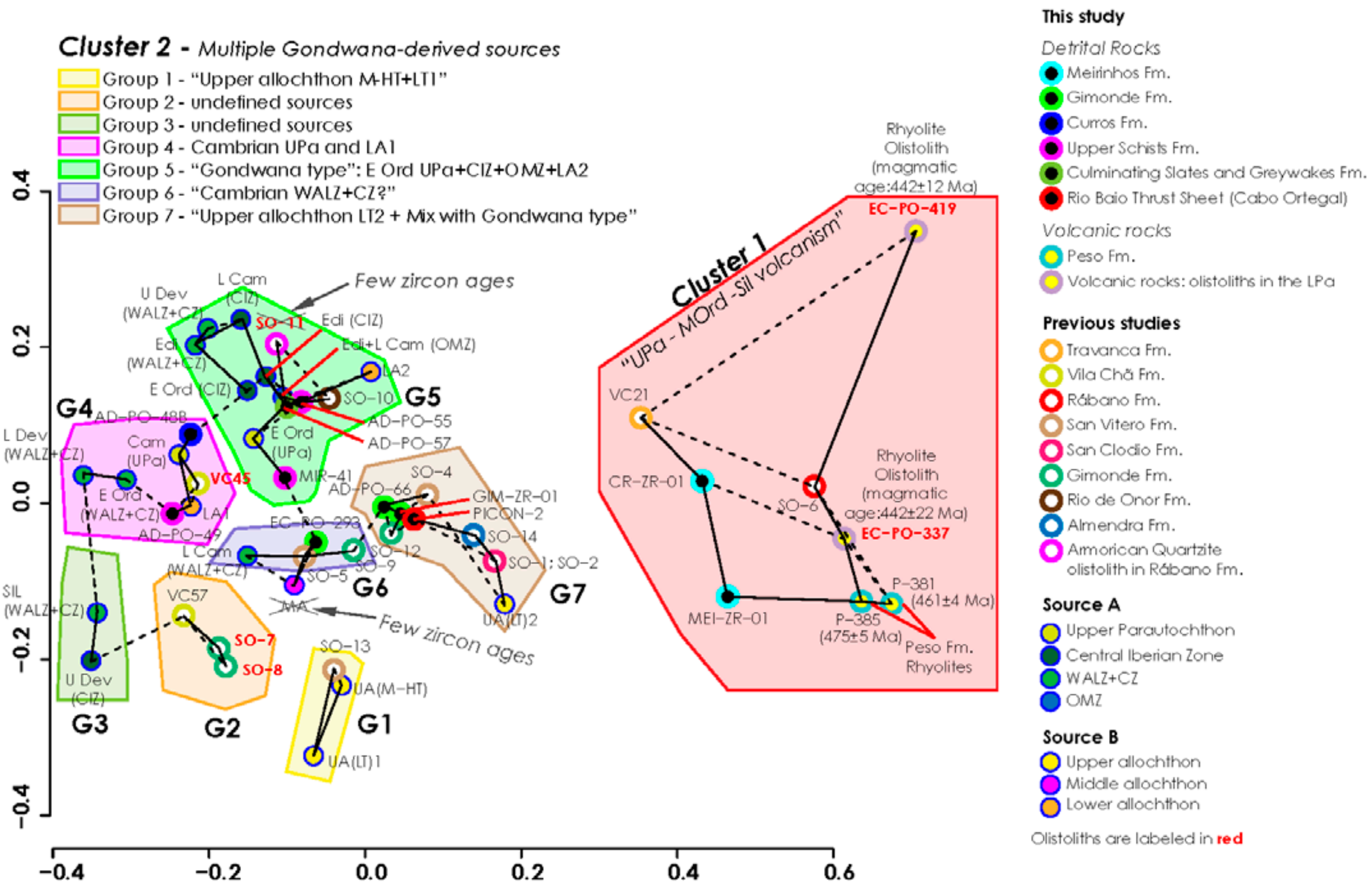

**Figure 10: MDS diagram for the studied samples and the reference populations in the autochthon and allochthon, with the differentiation between Cluster 1 (Fig. 11) and the seven groups of Cluster 2 (Fig. 12). Data to construct this plot is provided in the Supplementary tables 18 and 19. See more details on how this diagram was built in Supplementary File.** 1105

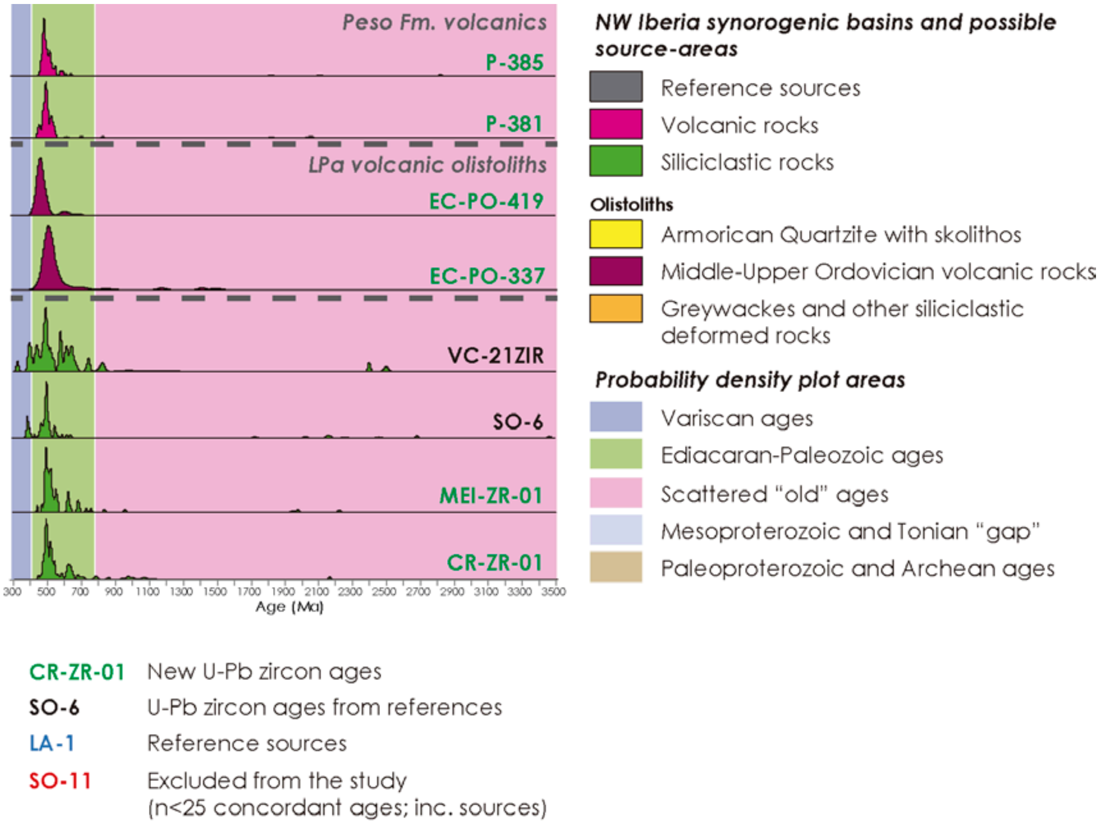

**Figure 11: Age distribution plots of the Cluster 1 type populations: "Upper Parautochthon Middle Ordovician-Silurian volcanism". See text and Supplementary File for a detailed description.**

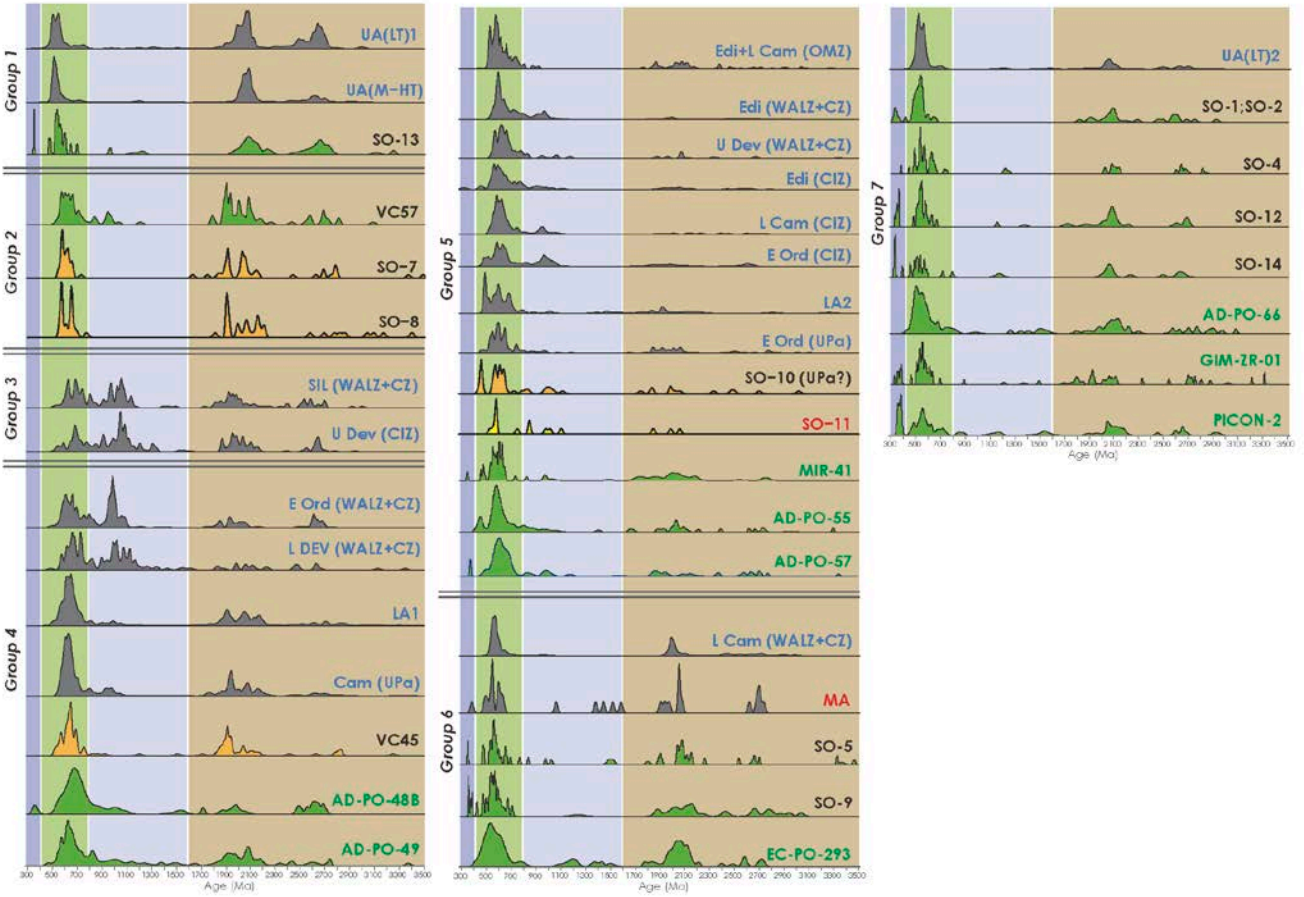

**Figure 12: Age distribution plots of all groups belonging to the Cluster 2 populations: "Multiple Gondwana-derived sources". Legend is in Fig. 11. See text and Supplementary File for a detailed description.**

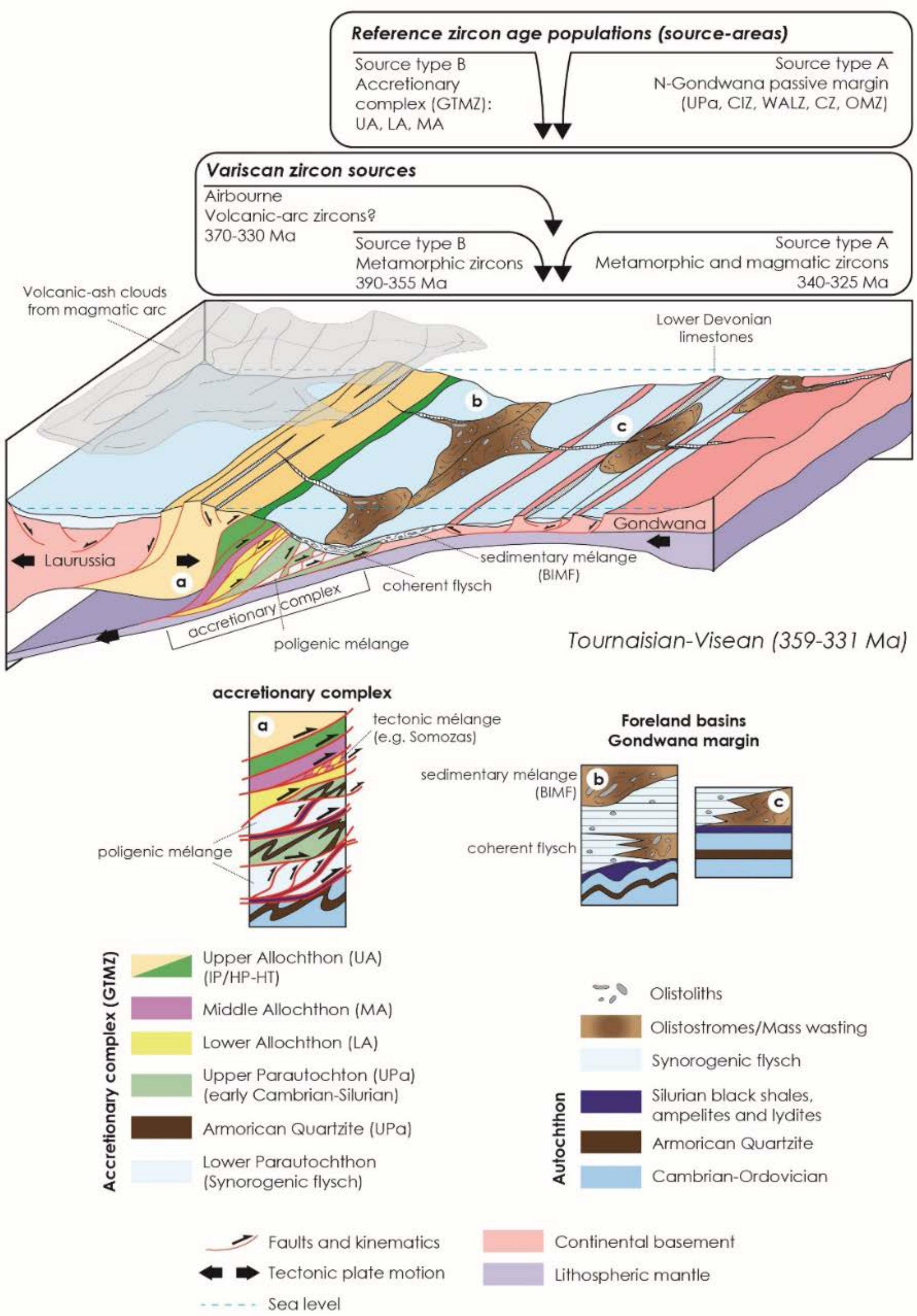

**Figure 13: Sketch of the orogenic collision at the Tournaisian-Visean displaying the trench-fill turbidites and the block-in-matrix deposits. The upper part represents the input of the zircon populations from different sources and zones.**

**Table 1: UTM coordinates and short description of the 17 samples gathered in this work.**

| SAMPLE ID | UTM system | Zone | Easting | Northing | Short description |
|---|---|---|---|---|---|
| **DETRITAL** | | | | | |
| PICÓN-2 | WGS84 | 29T | 601064 | 4844313 | Fine-grained black quartzites with pyrite and black pelite laminations |
| EC-PO-293 | WGS84 | 29T | 675598 | 4642546 | Quartz lithic sandstone (Gimonde type); impure grey quartzites <10cm clasts. |
| GIM-ZR-01 | WGS84 | 29T | 674114 | 4644518 | Lithic microconglometate, lithic-sandstones and phyllite rhythms. Light brown colour. |
| AD-PO-66 | WGS84 | 29T | 673233 | 4643613 | Quartz lithic sandstone and phyllite rhythm. Feldspar and quartz eyes: pyroclastic? |
| AD-PO-48B | WGS84 | 29T | 621227 | 4596860 | Massive fine grain sanstone. |
| AD-PO-57 | WGS84 | 29T | 642881 | 4597741 | Quartz lithic sandstone and phyllite rhythm (cm-dm). |
| AD-PO-55 | WGS84 | 29T | 644424 | 4595258 | Quartz lithic sandstone and phyllite rhythms. Fining upwards. |
| AD-PO-49 | WGS84 | 29T | 645744 | 4594231 | Quartz lithic sandstone and phyllite rhythms (cm-dm). |
| MIR-41 | WGS84 | 29T | 645735 | 4594230 | Quartz lithic sandstone and phyllite rhythmss (cm-dm). |
| MEI-ZR-01 | WGS84 | 29T | 683703 | 4569953 | Middle-grained greyish lithic sandstones with sedimentary laminations. |
| CR-ZR-01 | WGS84 | 29T | 678159 | 4569706 | Greenish-grey fine grained massive quartz lithic sandstone. |
| **OLISTOLITHS** | | | | | |
| EC-PO-337 | WGS84 | 29T | 692792 | 4642324 | Rhyodacitic pyroclastic tuff, quartz eyes and shards. Inside quartz lithic sandstone. |
| EC-PO-419 | WGS84 | 29T | 663291 | 4643585 | Acidic pyroclastic tuff, quartz eyes and S2 pervasive foliation. |
| PET-01 | WGS84 | 29T | 706355 | 4638642 | Massive reddish rhyolite. Py crystals. Grey when fresh. |
| RAB-01 | WGS84 | 29T | 730014 | 4628291 | Whittish rhyclitic pyrockastic tuff. Quartz eyes and shards.  Inside grey fine sandstone. |
| **UPPER PARAUT** | | | | | |
| P-381 | WGS84 | 29T | 674426 | 4603329 | Intenselly foliated white rhyolite with quartz phenocrysts |
| P-385 | WGS84 | 29T | 681845 | 4609510 | Foliated dacites with quartz, feldspar and plagioclase phenocrysts |