Space and time in the tectonic evolution of the northwestern Iberian Massif: Implications for the Variscan belt

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ABSTRACT

Recent advances in geochemical studies of igneous rocks, isotopic age data for magmatism and metamorphism, quantitative pressure-temperature *(P-T)* estimates of metamorphic evolution, and structural geology in the northwestern Iberian Massif are integrated into a synthesis of the tectonic evolution that places the autochthonous

and allochthonous terranes in the framework of Paleozoic plate tectonics. Because northwestern Iberia is free from strike-slip faults of continental scale, it is retrodeformable and preserves valuable information about the orthogonal component of convergence of Gondwana with Laurentia and/or Baltica, and the opening and closure of the Rheic Ocean.

The evolution deduced for northwest Iberia is extended to the rest of the Variscan belt in an attempt to develop a three-dimensional interpretation that assigns great importance to the transcurrent components of convergence. Dominant Carboniferous dextral transpression following large Devonian and Early Carboniferous thrusting and recumbent folding is invoked to explain the complexity of the belt without requiring a large number of peri-Gondwanan terranes, and its ophiolites and high-pressure allochthonous units are related to a single oceanic closure.

Palinspastic reconstruction of the Variscan massifs and zones cannot be achieved without restoration of terrane transport along the colliding plate margins. A schematic reconstruction is proposed that involves postcollisional strike-slip displacement of ~3000 km between Laurussia and Gondwana during the Carboniferous.

Keywords: Variscan belt, exotic terranes, accretionary history, strike-slip tectonics, Iberian Massif.

INTRODUCTION

A paleogeographic continental reconstruction for the late Paleozoic (Fig. 1) shows that three important Paleozoic belts, the northern Appalachians, the British and Scandinavian Caledonides, and the North German–Polish Caledonides, meet relatively close to the NW corner of the Iberian Massif. These belts mark the collision of three continental masses, Laurentia, Baltica, and Avalonia, which closed the Iapetus and Tornquist Oceans (which had opened during the Late Proterozoic and early Paleozoic). Avalonia likely formed close to Gondwana, because of its fauna (Cocks and Fortey, 1988), and it could also be considered a part of the Pan-African assemblage. It is viewed as a microcontinent or terrane assemblage detached from Gondwana in the Late Cambrian–Early Ordovician. It drifted away, creating the Rheic Ocean, and its subsequent closure during the Devonian gave rise to the Variscan belt in central and western Europe and northern Africa and to the Alleghanian orogen in North America (Hatcher, 1989, 2002; Winchester et al., 2002; van Staal et al., 1998).

Oceanic closure, which ultimately led to the formation of Pangea, occurred in several steps and gave rise to three groups of orogenic episodes, which are themselves diachronous. The first convergence-related events took place between the Late Cambrian and the Middle Ordovician. They have been described in the Scandinavian and British Caledonides (Finnmarkian and Grampian, respectively) and in the Appalachians (Taconic and Penobscottian), and they were related to arc-continent collisions in both sides of the Iapetus realm (Kelling et al., 1985; Hossack and Cooper, 1986; Stephens and Gee, 1989; van Staal, 2005; van Staal et al., 1998, this volume).

The second group of events took place between the Early Silurian and Late Devonian and was induced by the closure of Iapetus and the collision of Laurentia with Baltica (Scandian) in the north, and Laurentia with Avalonia in the south (Soper, 1988; Rey et al., 1997). Details of the latter include the accretion of Ganderia—an arc formed at the Avalonian side of Iapetus—to Laurentia in the Early Silurian (Salinic), the collision of Avalonia in the Late Silurian–Early Devonian (Acadian), and subsequent dextral transpression during the late Early Devonian–Early Carboniferous (Neoacadian) (van Staal et al., 1998; Winchester et al., 2002; van Staal, 2005). Deformation and metamorphism occurred at the same time in exotic terranes that were later incorporated to the Variscan belt. They have been referred to as Ligerian (Cogné, 1977; Faure et al., 1997) and Eo-Variscan or early Variscan events, and they have been described in the Bohemian Massif (Franke, 2000; Franke and Zelazniewicz, 2002), the French Massif Central (Santallier et al., 1994), the Armorican Massif (Ballèvre et al., 1994), the Alps (von Raumer and Neubauer, 1993, 1994), and northwestern Iberia (Gómez Barreiro et al., 2006, 2007; Fernández-Suárez et al., this volume).

The third group of events spanned the Carboniferous and Early Permian, and it gave rise to intense deformation in Europe and Africa (Variscan) and the Appalachians (Alleghanian). These events resulted from the closure of the Rheic and Theic Oceans and collision of Gondwana with the previously formed Laurussia continent (Laurentia, Baltica, and Avalonia; Lefort, 1989).

The Variscan-Appalachian belt is linear but sinuous, with several oroclinal bends. In Europe (Fig. 2), the belt runs between two arcuate structures, the Bohemian Massif (Franke and Zelazniewicz, 2002) and the Iberian-Armorican arc (Bard et al., 1971; Ribeiro et al., 1995). An additional feature of the Variscan-Appalachian belt is the extent of transcurrent movements that have been active during most, if not all of the orogeny, and that have resulted in the terrane dispersion that hinders paleogeographic restoration (Gates et al., 1986; Hatcher, 1989, 2002; Martínez Catalán, 1990; Shelley and Bossière, 2000, 2002).

The northwestern corner of the Iberian Massif includes the Spanish regions of Galicia and the Cantabrian Mountains, as well

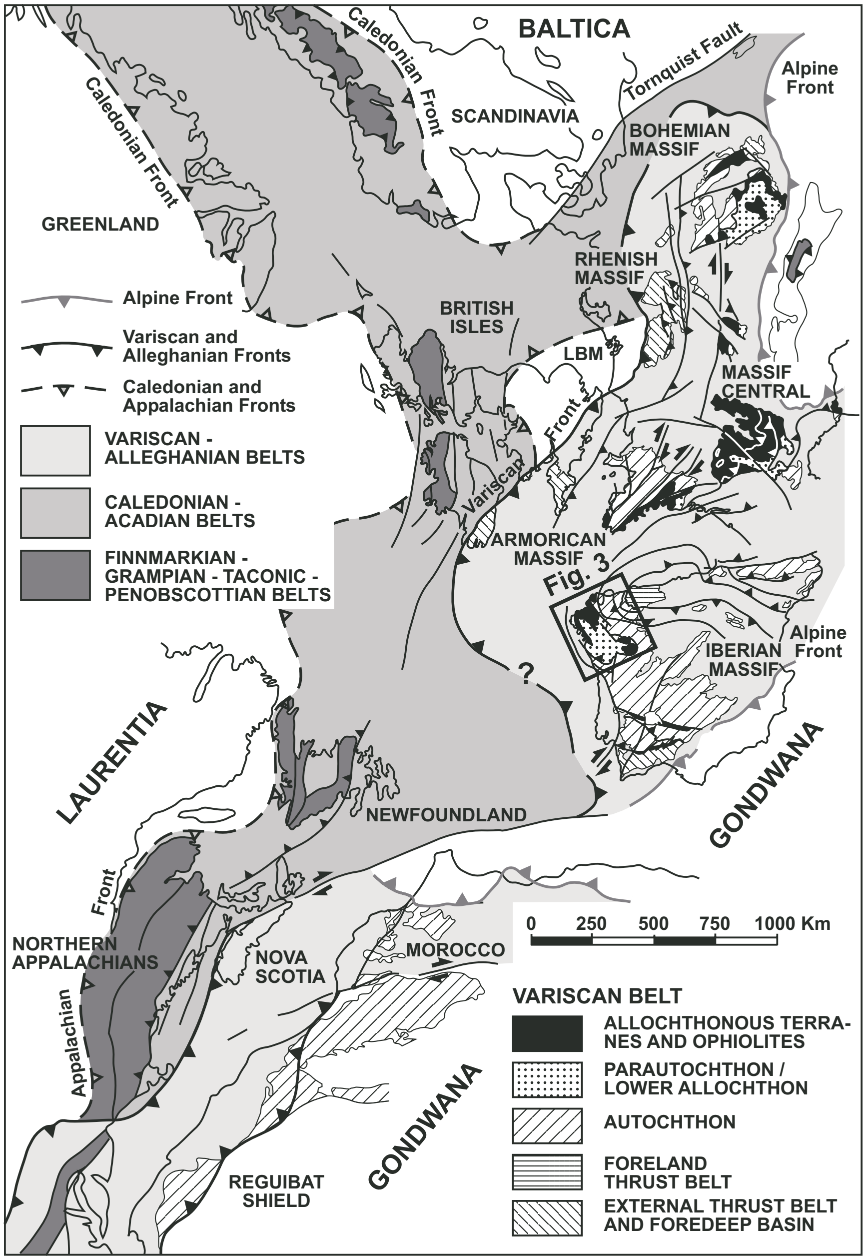

Figure 1. Sketch showing the position of Iberia in relation to the Appalachian, Caledonian, and Variscan belts at the end of Variscan convergence (modified from Martínez Catalán et al., 2002). LBM—London-Brabant Massif.

as northern Portugal, and it is located at the hinge zone of the Iberian-Armorican arc (Figs. 2 and 3). Coherent with its setting inside the Variscan mobile belt, the region preserves relics of one of the oceanic realms that once separated the early Paleozoic continents and recorded large amounts of orogenic shortening during their amalgamation. Strike-slip faults and shear zones exist but are not of continental scale, which implies that the Galician–northern Portugal section, including the Cantabrian Mountains, is retrodeformable and provides information about the orthogonal components of Gondwana-Laurussia plate convergence.

The northwestern Iberian basement consists of plutonic and metamorphic rocks with grades ranging from very low to catazonal, and a clear separation can be established between autochthonous and allochthonous terranes. The autochthon consists of a thick metasedimentary sequence deposited in northern Gondwana during the Late Proterozoic and Paleozoic, whereas the allochthon consists of the remnants of a huge and structurally complex nappe pile preserved in the core of late Variscan synforms. Both are separated by a thrust sheet, several kilometers thick, consisting of metasediments and volcanics derived

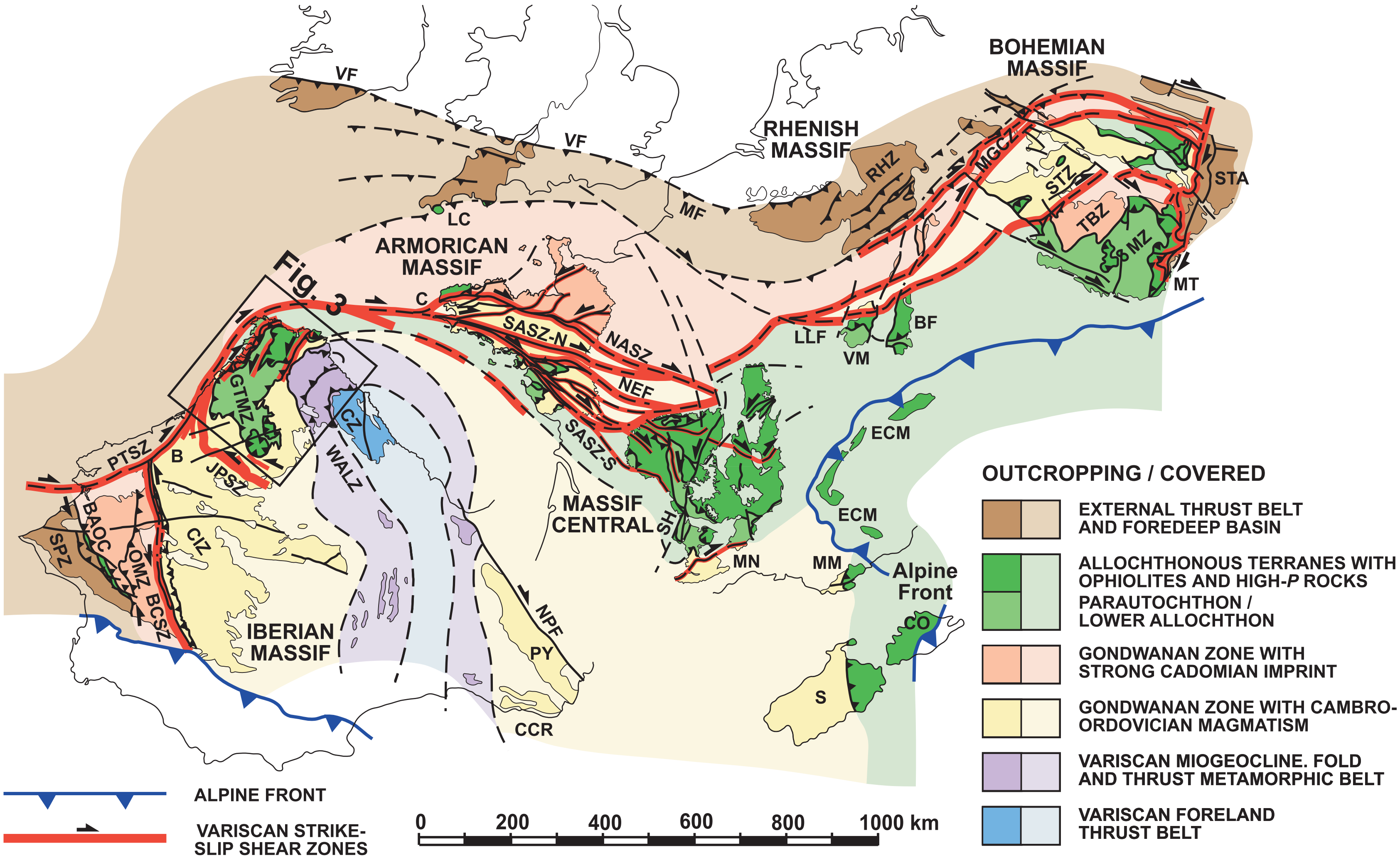

Figure 2. Subdivision of the Variscan belt showing the allochthonous terranes and the main transcurrent shear zones. Abbreviations: B—Buçaco; BAOC—Beja-Acebuches ophiolitic complex; BCSZ—Badajoz-Córdoba shear zone; BF—Black Forest; C—Crozon; CCR—Catalonia Coast Ranges; CIZ—Central Iberian zone; CO—Corsica; CZ—Cantabrian zone; ECM—External crystalline massifs of the Alps; GTMZ—Galicia-Trás-os-Montes zone; JPSZ—Juzbado-Penalva shear zone; LC—Lizard Complex; LLF—Layale-Lubine fault; MF—Midi fault; MGCZ—Mid-German crystalline zone; MM—Maures Massif; MN—Montagne Noire; MT—Moldanubian thrust; MZ—Moldanubian zone; NASZ—North Armorican shear zone; NEF—Nort-sur-Erdre fault; NPF—North Pyrenean fault; OMZ—Ossa-Morena zone; PTSZ—Porto-Tomar shear zone; PY—Pyrenees; RHZ—Rhenian-Hercynian zone; S—Sardinia; SASZ—South Armorican shear zone (N and S—northern and southern branches); SH—Sillon Houillier; SPZ—South Portuguese zone; STA—Silesian terrane assemblage; STZ—Saxo-Thuringian zone; TBZ—Teplá-Barrandian zone; VF—Variscan front; VM—Vosges Massif; WALZ—West Asturian-Leonese zone.

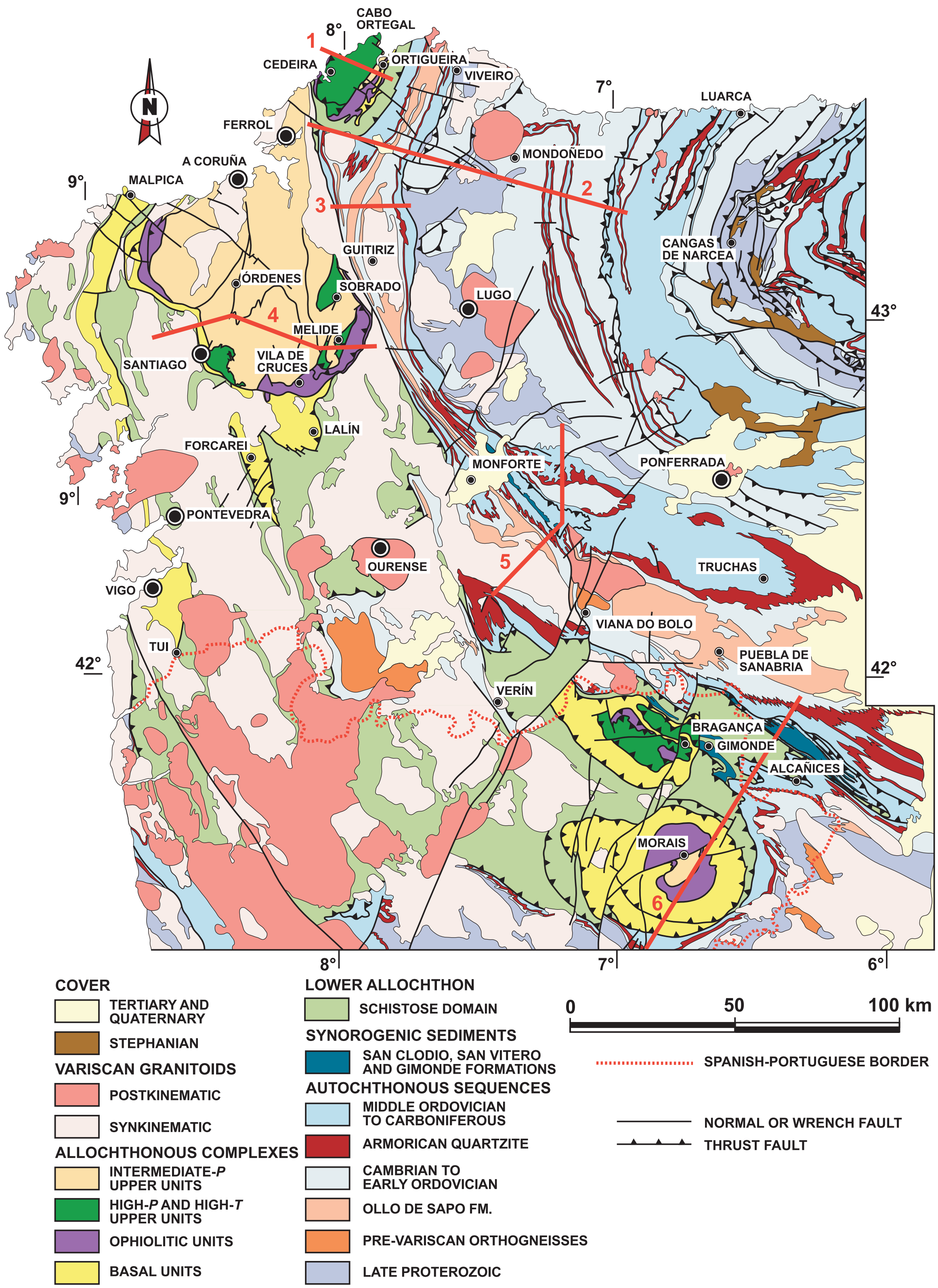

Figure 3. Geological sketch map of northwestern Iberia, showing the allochthonous complexes and their units. For location, see Figures 1 and 2. The locations of cross sections in Figure 4 are indicated.

from the outer margin of Gondwana (Farias et al., 1987), often described as a parautochthon (Ribeiro et al., 1990). However, because stratigraphic continuity with the autochthon is broken (Valverde-Vaquero et al., 2005), it will be referred to here as the lower allochthon. The allochthonous terranes, together with the lower allochthon, are included in the so-called Galicia-Trás-os-Montes zone (Farias et al., 1987).

TECTONIC SETTING OF ALLOCHTHONOUS TERRANES

There are three allochthonous complexes in Galicia (Cabo Ortegal, Órdenes, and Malpica-Tui), and two in northern Portugal (Bragança and Morais). They consist of a pile of allochthonous units characterized by unique lithologic associations and tectonometamorphic evolution. These units are separated from each other by faults, either thrusts or extensional detachments (Figs. 3 and 4). Three groups of allochthonous units can be recognized from bottom to top in ascending structural order: basal, ophiolitic, and upper units.

The basal units form a rather continuous thrust sheet consisting of schists and paragneisses alternating with felsic and mafic igneous rocks, of which granitic and peralkaline orthogneisses have yielded Rb-Sr and U-Pb ages of 490–470 Ma (Van Calsteren et al., 1979; García Garzón et al., 1981; Santos Zalduegui et al., 1995). The bimodal, partially alkaline magmatism reflects Ordovician rifting (Ribeiro and Floor, 1987; Pin et al., 1992). Since the basal units are not separated from the lower allochthon by ophiolites, it is assumed that they were part of Gondwana. Because the ophiolitic units overlie them, they are viewed as fragments of the most external edge of the Gondwanan continental margin. The Early Ordovician magmatism, partly peralkaline, probably resulted from the drift of a broken-away peri-Gondwanan terrane.

The ophiolitic units crop out discontinuously surrounding the upper units (Fig. 3) and form part of a formerly continuous and strongly imbricated nappe stack with at least two different types of ophiolite (see Arenas et al., this volume; Sánchez Martínez et al., this volume). Ophiolitic units occupying a relatively higher structural position represent the basal section of an ophiolite sequence that contains serpentinized harzburgitic ultramafic rocks, pegmatitic gabbros, and diabase dikes. Their geochemistry indicates a suprasubduction character, whereas zircons from leucogabbros yield a concordant U-Pb age of 395 Ma (Díaz García et al., 1999; Pin et al., 2002), providing evidence for oceanic crust generation, and consumption, in Early Devonian time. The structurally lower ophiolitic units consist of greenschist-facies volcanic and plutonic mafic rocks (greenstones) and metapelites, with rare felsic orthogneisses, serpentinites, and cherts—all strongly deformed.

The upper units occupy the core of the allochthonous complexes (Fig. 4) and have been subdivided according to their metamorphic evolution into high-pressure (*P*) and high-temperature (*T*) upper units, below, and intermediate-*P* upper units, above. Both groups consist of terrigenous metasediments, orthogneisses, and metabasites, with the additional presence of ultramafic rocks in the high-*P* and high-*T* upper units. The metabasites include metagabbros, eclogites, high-*P* and high-*T* mafic granulites, and amphibolites. The gabbros and orthogneisses have yielded U-Pb ages around 500 Ma, whereas detrital zircons in the metasediments indicate a maximum depositional age of 480 Ma for the uppermost, greenschist-facies metagraywackes (Fernández-Suárez et al., 2003), and 507 Ma for the structurally lower, high-*P* and high-*T* paragneisses (Schäfer et al., 1993).

Most of the mafic rocks are metagabbros with tholeiitic compositions. Their geochemical signature has been compared to mid-ocean-ridge basalt (MORB) (Gil Ibarguchi et al., 1990) and related to continental rifting in the case of the high-*P* and high-*T* upper units (Galán and Marcos, 1997), whereas the intermediate-*P* upper units have arc-tholeiitic affinities (Andonaegui et al., 2002; Castiñeiras, 2003). The additional presence of intermediate plutonic rocks, such as diorites and tonalites, in the intermediate-*P* upper units, reinforces the interpretation that these rocks were generated in an arc setting. Furthermore, geochemical studies of the ultramafic rocks of Cabo Ortegal are consistent with this hypothesis (Santos et al., 2002).

In spite of the arc affinities shown by some of them, the upper units seem to represent a terrane that had drifted away from Gondwana. The oldest ages obtained from upper intercepts and inherited zircons from the upper units (between 2.7 and 1.8 Ga; Kuijper, 1980; Peucat et al., 1990; Dallmeyer and Tucker, 1993; Schäfer et al., 1993) and the basal units (1.8 Ga; Santos Zalduegui et al., 1995) are similar to those found in the orthogneisses of the autochthon (Lancelot et al., 1985; Gebauer, 1993), and they are also similar to those of the West African craton. These ages point to a common Gondwanan basement for the upper and basal units and for the Iberian autochthon. Moreover, detrital zircon ages have been determined for graywackes from low-grade metasediments of an intermediate-*P* upper unit in the Órdenes Complex, which yielded three age populations of 2.5–2.4 Ga, 2.1–1.9 Ga, and 610–480 Ma (Fernández-Suárez et al., 2003), which also record the major events in the West African craton of northern Gondwana.

On the other hand, Late Cambrian to Early Ordovician magmatism is widespread, not only in the allochthonous units, but also in the autochthon, and is a little older in the upper units (ca. 500 Ma; Dallmeyer and Tucker, 1993; Abati et al., 1999) than in the basal units or the autochthon (490–470 Ma; Van Calsteren et al., 1979; García Garzón et al., 1981; Vialette et al., 1987; Santos Zalduegui et al., 1995; Gebauer, 1993; Valverde Vaquero and Dunning, 2000). Magmatism has calc-alkaline and arc affinities in the autochthon (Ortega et al., 1996), in some of the allochthonous upper units, and in many granitoids of the allochthonous basal units, but some granites and mafic rocks of the latter are alkaline to peralkaline (Floor, 1966; Pin et al., 1992).

To reconcile the tectonic stability registered by the Early Ordovician passive-margin sediments of the autochthon (Pérez-Estaún et al., 1991), the rift-related magmatism of the basal units,

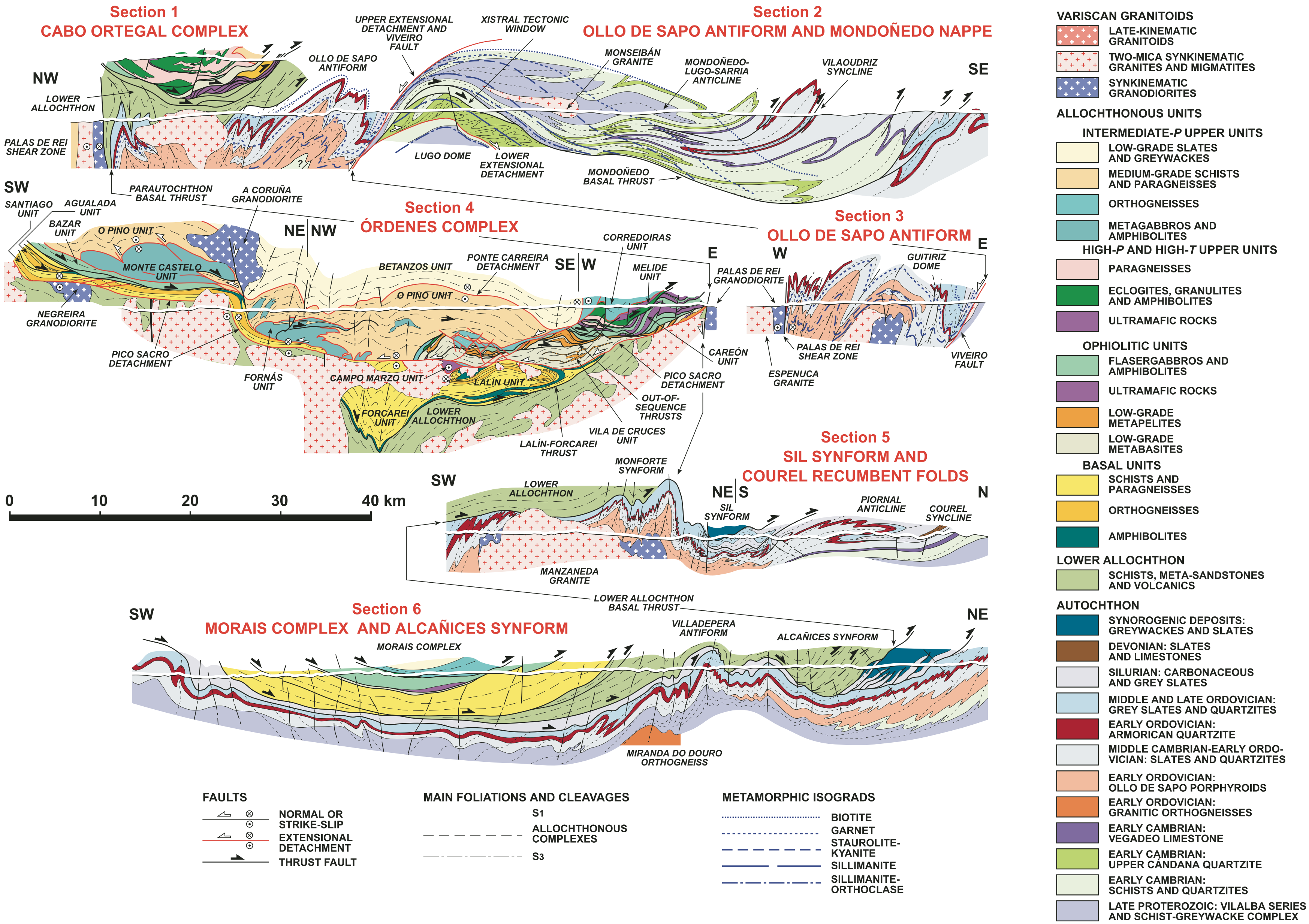

Figure 4. Geological sections across central and eastern Galicia and northern Portugal showing the main Variscan structures. Isograds of Variscan regional metamorphism have been drawn in sections 1, 2, and 3 to show their relationships to folding. See Figure 3 for locations. Sections are based on the following contributions: 1—Marcos et al. (1984) and Arenas (1988); 2—Bastida et al. (1982) and Martínez Catalán et al. (2003); 3—González Lodeiro et al. (1981); 4—Martínez Catalán et al. (2002); 5—Martínez Catalán et al. (2004); 6—Ribeiro (1974) and González Clavijo and Martínez Catalán (2002).

the widely accepted early Paleozoic terrane dispersion in the peri-Gondwanan realm, and the calc-alkaline and arc affinities in the upper units and the autochthon, Valverde Vaquero and Dunning (2000) suggested that the rifting was located in a back-arc setting behind a subduction zone. This hypothesis is supported in reconstructions of peri-Gondwanan terranes by Stampfli et al. (2002), Winchester et al. (2002), von Raumer et al. (2003), and van Staal et al. (1998). Rollback of the subducting slab may have pulled Avalonia apart from Gondwana, and also the terrane partially preserved in the Galician upper allochthonous units. This terrane was possibly part of a discontinuous continental ribbon in the eastern continuation of Avalonia (Gómez Barreiro et al., 2007), and it recorded active-margin arc-related magmatism during separation (Fig. 5).

OROGENIC EVOLUTION: THE CROSS-SECTION VIEW

Early Variscan Accretionary History

In the upper allochthonous units, there is an increase in metamorphic grade from top to bottom, showing a transition from the uppermost epizonal units to mesozonal and catazonal units below. U-Pb dating of metamorphism has yielded two main age populations (Schäfer et al., 1993; Santos Zalduegui et al., 1996; Abati et al., 1999; Ordóñez Casado et al., 2001; Fernández-Suárez et al., 2002a, this volume). The older, dated around 500–490 Ma on monazite, whole zircon grains, and magmatic domains in zircon, is coeval with widespread magmatism and probably reflects high-*T* and low- to intermediate-*P* metamorphism in the magmatic arc. The younger age population, dated between 410 and 390 Ma in monazite, zircon, and metamorphic overgrowths of zircon, is linked to initial Variscan convergence and high-*P* and high-*T* metamorphism. In fact, start of Variscan convergence should be older, because 410 Ma would be the age of decompression melting associated with the onset of exhumation (Fernández-Suárez et al., this volume). Actually, $^{40}Ar/^{39}Ar$ data, which give a ca. 425 Ma age for retrogressive amphibolite-facies foliation in high-*P* and high-*T* units, suggest an even older age for the high-*P* and high-*T* metamorphism (Dallmeyer et al., 1997; Gómez Barreiro, 2004; Gómez Barreiro et al., 2006).

This compressional event of Silurian to Early Devonian age produced a thick metamorphic pile, and the deep parts register pressures of 1.8 GPa or higher (Gil Ibarguchi et al., 1990; Mendia Aranguren, 2000). Thickening of the upper units and the subduction of some of them probably reflect their underthrusting following accretion to a large continental mass, either Baltica or Laurentia (Fig. 5). Accretion was followed by retrograde amphibolite-facies metamorphism in the lower parts of the accretionary wedge at 390–375 Ma (Dallmeyer et al., 1991, 1997; Valverde Vaquero and Fernández, 1996) related to the beginning of exhumation. The fact that units with differences of more than 1.2 GPa in peak pressure occur presently in a sheet less than 10 km thick indicates that the original pile has been largely attenuated. Actually, the different upper units are separated from each other by extensional faults (Figs. 4 and 5), interpreted as detachments developed in different stages of their stacking and emplacement (Martínez Catalán et al., 2002).

The ophiolitic units were stacked in several slices (Díaz García et al., 1999) and reached metamorphic conditions ranging between 625 °C and 680 °C and 1.1 and 1.2 GPa. Amphibolite-facies prograde metamorphism, dated at 390–380 Ma (Dallmeyer and Gil Ibarguchi, 1990; Dallmeyer et al., 1991, 1997), was coeval with retrograde metamorphism in the upper units, thus suggesting that underthrusting and imbrication of oceanic lithosphere caused exhumation of the overlying upper units (Fig. 5).

The basal units record a high-*P* regional metamorphic event not found in the lower allochthon or in the autochthon. Peak pressures reached 1.5–1.7 GPa in a west-directed subduction zone (in present coordinates), as deduced from the pressure gradient along both limbs of a huge recumbent anticline (Fig. 4, section 4; Arenas et al., 1995; Martínez Catalán et al., 1996). Subduction may have started ca. 380 Ma and ended ca. 365 Ma (Van Calsteren et al., 1979; Santos Zalduegui et al., 1995; Rodríguez et al., 2003).

Variscan Collisional Deformation: Thrust and Nappe Tectonics

The structural evolution of the autochthon and lower allochthon is relatively simple, and the structures are related to three main compressional events that developed during convergence following collision (Pérez-Estaún et al., 1991). The first event (D_1) produced recumbent folds with east vergence and axial planar cleavage (S_1), which is the oldest penetrative fabric recognized. Large D_1 folds occur in the Mondoñedo nappe (Fig. 4, section 2): the Mondoñedo-Lugo-Sarria anticline and the Vilaoudriz syncline (Matte, 1968; Bastida et al., 1986). Their common overturned limb reaches 15–30 km due to late horizontal shearing related partly to thrusting and partly to late orogenic extension. To the west, recumbent folds are common in low-grade areas, but they are smaller, and their reverse limbs rarely attain 5 km.

The youngest deposits preserved in the core of one of the recumbent synclines are Early Devonian (Fig. 4, section 5), and $^{40}Ar/^{39}Ar$ dating of regional S_1 cleavage yielded ages of 359 Ma close to the allochthonous complexes and 336 Ma to the east, far away from them and adjacent to the Cantabrian zone (Dallmeyer et al., 1997). When compared with deformation ages in the allochthonous units, S_1 in the autochthon developed immediately after the greenschist-facies foliation in the structurally lower ophiolites (363–367 Ma; Dallmeyer et al., 1997) and the end of subduction-related metamorphism in the basal units (365 Ma; Rodríguez et al., 2003). It seems that once continental subduction of the outermost edge of Gondwana became locked, shortening began in inner parts of its continental platform, giving rise first to recumbent folds (D_1), and then to large thrust sheets, described as the second deformational event (D_2).

Four large thrusts developed in the internal zones of northwestern Iberia (Figs. 4 and 5). The Lalín-Forcarei thrust carried

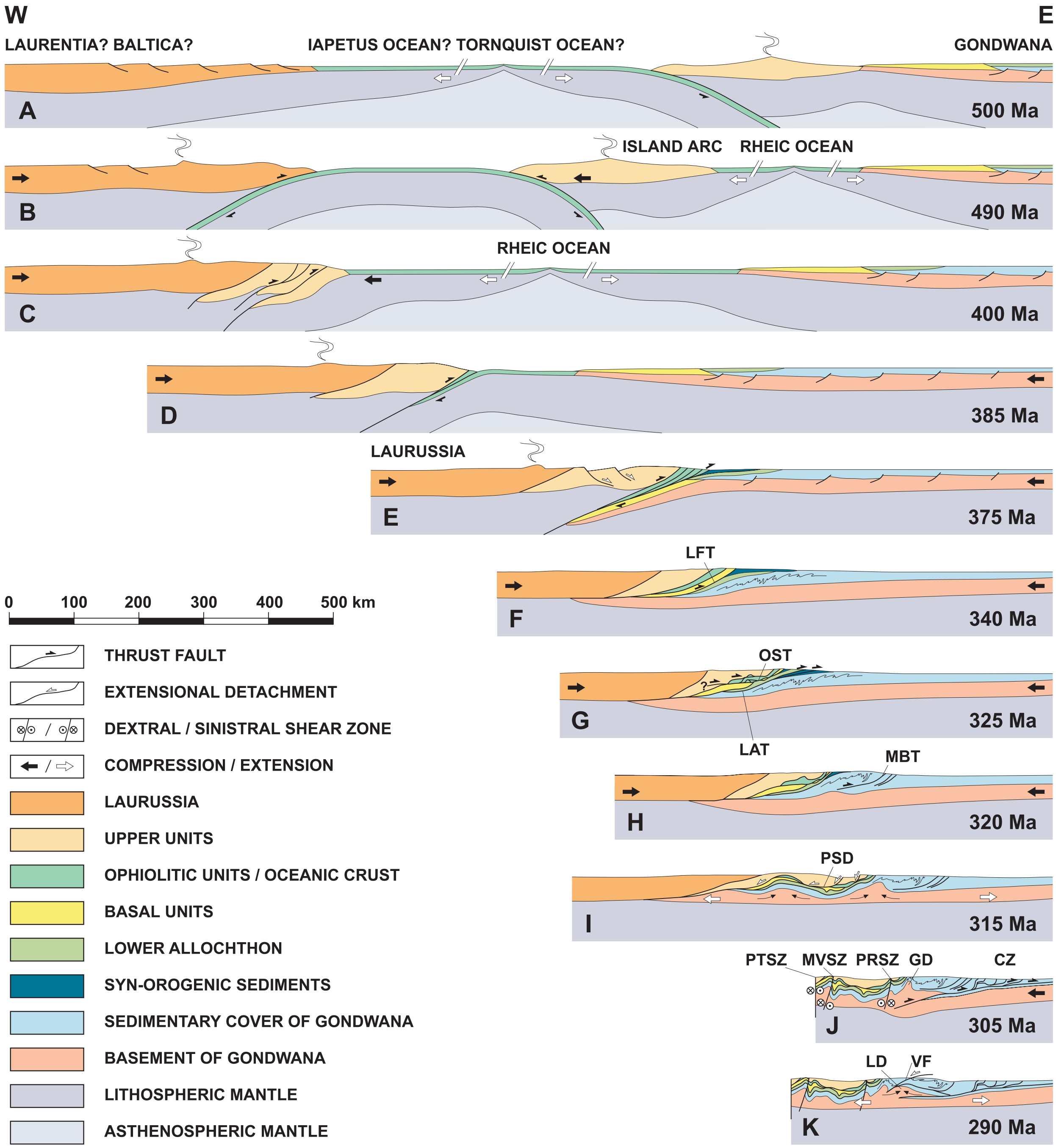

Figure 5. Proposed stages in the tectonic evolution of northwest Iberia. A: Individualization of a peri-Gondwanan terrane by slab rollback, and arc-related magmatic activity during the Late Cambrian to Early Ordovician. B: Drifting of the peri-Gondwanan terrane away from Gondwana and spreading of the Rheic Ocean. C: Building of an accretionary wedge by underthrusting and imbrication of the peri-Gondwanan terrane during the Silurian to Early Devonian. D: Closure of the Rheic Ocean and imbrication of oceanic slices. E: Subduction of outer edge of the Gondwanan continental margin in the Middle to Late Devonian. F: Thrusting of allochthonous units over the lower allochthon during the Early Carboniferous. G: Development of out-of-sequence thrusts in the Early to Middle Carboniferous. H: Thrusting in more external parts of the belt during the Middle Carboniferous. I: Collapse and extension of Gondwanan thickened crust with formation of extensional detachments and domes. J: Late upright folding, strike-slip faulting, and thin-skinned tectonics in the foreland during the Late Carboniferous. K: Extensional collapse migrates to the east, probably in response to crustal thickening induced by underthrusting of basement to the west during thin-skinned shortening in the foreland. Note that W-E coordinates correspond to present. Past coordinates might have varied from NE-SW to NW-SE during the time interval covered by the cartoon, according to the paleoposition of continental masses in the reconstruction by Winchester et al. (2002). Abbreviations: CZ—Cantabrian zone; GD—Guitiriz dome; LAT—lower allochthon thrust; LD—Lugo dome; LFT—Lalín-Forcarei thrust; MBT—Mondoñedo basal thrust; MVSZ—Malpica-Vigo shear zone; OST—out-of-sequence thrusts; PRSZ—Palas de Rei shear zone; PSD—Pico Sacro detachment; PTSZ—Porto-Tomar shear zone; VF—Viveiro fault.

the basal units over the lower allochthon after 346 Ma, which is the age of migmatization in allochthonous paragneisses (U-Pb in monazite and rutile; Abati and Dunning, 2002). The S_2 cleavage in the underlying lower allochthon, which developed during emplacement of the Lalín-Forcarei thrust, was dated at 340 Ma ($^{40}Ar/^{39}Ar$; Dallmeyer et al., 1997). The upper and ophiolitic allochthonous units subsequently moved over the basal units and the lower allochthon, becoming strongly imbricated along the sole thrust. As they had been previously stacked and internally imbricated in sequence, the new thrust system developed out of sequence (Martínez Catalán et al., 2002). The age of the out-of-sequence thrusts is constrained between 340 Ma, age of the Lalín-Forcarei thrust, and 323 ± 11 Ma, age of the Palas de Rei granodiorite (Bellido et al., 1992), or 317 ± 15 Ma, age of the Espenuca granite (Ortega Cuesta, 1998), both of which postdate nappe emplacement and predate the Pico Sacro extensional detachment. A 325 Ma $^{40}Ar/^{39}Ar$ age obtained by Dallmeyer et al. (1997) in an ultramylonite from a high-*P* and high-*T* upper unit may be a representative age for the out-of-sequence thrusts.

The isotopic data are consistent with the age and structural relationships of synorogenic flysch deposits that crop out close to the eastern boundary of the Bragança Complex in Portugal, in the Alcañices synform in Zamora, and in a narrow synform in central Galicia (Fig. 3; Fig. 4, sections 5 and 6). They consist of low-grade slates, graywackes, and conglomerates with plant debris and metamorphic pebbles (Riemer, 1966; Matte, 1968; Martínez García, 1972; Pérez-Estaún, 1974; Ribeiro and Ribeiro, 1974) cropping out in imbricates inside and in front of the lower allochthon thrust sheet (González Clavijo and Martínez Catalán, 2002; Martínez Catalán et al., 2004). The synorogenic deposits are turbiditic and have been dated as Late Devonian (Frasnian) in Portugal, using palynomorphs (Pereira et al., 1999), and as early Namurian using the age of the youngest detrital zircon in the Sil synform in central Galicia (Martínez Catalán et al., 2004). Here, zircon age populations are more compatible with those of the allochthonous terranes than with the autochthon because they lack the 1.1–1 Ga Mesoproterozoic population, which is well represented in the autochthonous succession (Fernández-Suárez et al., 2000b, 2002b; Martínez Catalán et al., 2004). This suggests that the synorogenic turbidites were deposited in a trough that developed in front of the allochthonous terranes during their emplacement by thrusting (González Clavijo and Martínez Catalán, 2002; Martínez Catalán et al., 2004). Their age is older near the Bragança Complex than in central Galicia, which reflects the advance of the allochthonous sheet.

The emplacement of the lower allochthon, carrying the allochthonous terranes piggyback, took place along a nearly horizontal detachment, the lower allochthon thrust. It has an apparent displacement of nearly 200 km and is a wonderful example of thin-skinned tectonics in the hinterland of a collisional belt (Fig. 4, sections 5 and 6). Silurian carbonaceous slates were the weak layer that accommodated the detachment, and they became strongly phyllonitized (Farias et al., 1987; Farias Arquer, 1990; González Clavijo and Martínez Catalán, 2002; Marcos and Llana Fúnez, 2002). The low amplitude of the previous (D_1) recumbent folds left the stratigraphic sequence nearly undisturbed, allowing the thrust surface to utilize the graphite-rich Silurian slates. Fan-like imbricates at the lower allochthon thrust front are well preserved in the Alcañices synform (González Clavijo and Martínez Catalán, 2002). In the Sil synform, the younger detrital zircon (dated 324 ± 7 Ma) constrains the age of the lower allochthon thrust as late Visean–early Namurian (Martínez Catalán et al., 2004). Its motion was nearly synchronous with the later out-of-sequence thrusts, or somewhat younger.

The fourth large fault, the Mondoñedo basal thrust, developed further east, carrying the large recumbent folds previously formed and possibly enlarging their amplitude by ductile flow concentrated at its basal shear zone (Bastida et al., 1986; Aller and Bastida, 1993; Martínez Catalán et al., 2003). The precise age of the Mondoñedo basal thrust is unknown, but two thrust faults east of the Mondoñedo basal thrust were dated by Dallmeyer et al. (1997) at ca. 320 Ma.

Several other minor thrust faults developed to the east of the Mondoñedo basal thrust, and thrusting became very important in the Cantabrian zone (Figs. 2 and 5), a thin-skinned foreland thrust belt where these structures are the main ones responsible for orogenic shortening (Pérez-Estaún et al., 1988).

Variscan Orogenic Collapse and Late Variscan Folding

Closely following the emplacement of the allochthonous terranes and thrust imbrication of the autochthon, relatively deep parts of the crust underwent a temperature increase associated in part with decompression. A pervasive subhorizontal tectonic foliation developed in the middle and lower parts of the autochthonous section, from the biotite zone down to the deepest accessible parts of the crust, cropping out in the core of late-orogenic extensional domes. The foliation is a crenulation cleavage in the upper parts, but it passes quickly to a schistosity and a gneissose banding downward, in the sillimanite–K-feldspar zone.

Extension is demonstrated by the thinning and even disappearance of some of the previously metamorphic zones at several map-scale shear zones, equivalent to ductile detachments, and by the metamorphic evolution on both sides of them: isobaric heating at their hanging wall and isothermal decompression at their footwall (Escuder Viruete et al., 1994; Díez Balda et al., 1995; Arenas and Martínez Catalán, 2003; Martínez Catalán et al., 2004). Kinematic criteria demonstrate a noncoaxial component of deformation with a sense of shear that varies from one detachment to other and indicate extension normal, oblique, and parallel to the orogenic trend.

Extension occurred under the allochthonous terranes, and also to the east, in the Ollo de Sapo antiform and in the Mondoñedo nappe. For instance, the Pico Sacro detachment developed between the Órdenes Complex and the migmatite and granite assemblage below (Fig. 4, section 4; Fig. 5). The Guitiriz dome is also an extensional structure, which, as many others, evolved into a dome (Fig. 4, section 3; Fig. 5).

The Lugo dome (Fig. 4, section 2) developed in the internal parts of the Mondoñedo nappe, which has footwall units that crop out in two tectonic windows related to doming. There, internal extension and two extensional ductile detachments stretched the nappe and its relative autochthon and are responsible for most of the stretching undergone by the reverse limb of the two largest recumbent folds (Fig. 5). One of the extensional detachments affected the footwall unit, whereas the other strongly attenuated the thrust sheet and evolved into a brittle structure, the Viveiro fault, which cuts across the whole Mondoñedo nappe and its footwall unit (Arenas and Martínez Catalán, 2003; Martínez Catalán et al., 2003). The difference in peak pressure between both sides of the upper extensional detachment and the Viveiro fault has been estimated to be 0.4–0.5 GPa (Reche et al., 1998), roughly equivalent to a subtraction of 15–19 km by the shear zone and the fault.

One of the main characteristics of the geological map of northwestern Iberia is the alternation of domes and basins (Martínez et al., 1988), which in many cases implies crustal-scale boudinage enhanced by deep crustal flow. Heat accumulation due to crustal thickening and some advection of mantle-derived rocks (Galán et al., 1996) caused partial melting, lowering the viscosity of the middle and lower crust, and facilitated viscous flow that accommodated extension of the whole crust, probably in response to gravitational forces. High-grade autochthonous rocks—the youngest parageneses of which are high-*T* and low-*P*—crop out in the domes, accompanied by abundant Variscan granitoids, whereas the basins are occupied by low-grade autochthonous metasediments and, in five cases, by the remnants of the allochthonous terranes preserved as klippen (Fig. 3).

Late upright folds are related to the third compressional event (D_3) and are associated with a crenulation cleavage (S_3). D_3 macrostructures interfere with D_1 recumbent folds and are easy to identify because they fold the regional metamorphic isograds. Large D_3 folds commonly nucleated in previously developed domes and basins, and they vary from open to tight. Variations in flattening are due to heterogeneous strain associated with subvertical, transcurrent ductile shear zones (Iglesias Ponce de León and Choukroune, 1980).

The main phase of gravitational collapse and extension occurred between 320 and 310 Ma, which are the ages of many synkinematic granitoids (Fernández-Suárez et al., 2000a). This part of collapse is considered intra-orogenic for two reasons. One is that the extensional domes and basins were overprinted by upright folds and transcurrent ductile shear zones, as in the case of the Guitiriz dome (Fig. 4, section 3; Fig. 5). The other is that extension in the internal zone was followed by shortening in the Cantabrian zone (Figs. 2 and 5), a thin-skinned foreland thrust belt that developed to the east between 312 and 300 Ma (Pérez-Estaún et al., 1988).

Upright D_3 folds have been dated by synkinematic granitoids at 314 ± 6 Ma (Capdevila and Vialette, 1970; Ries, 1979), whereas strike-slip shear zones closely related to their development moved between 315 and 305 Ma (Regêncio Macedo, 1988; Valle Aguado et al., 2005).

However, the Lugo dome developed later, as demonstrated by $^{40}Ar/^{39}Ar$ cooling ages around 300 Ma (Dallmeyer et al., 1997), and also because the continuation to the south of the Viveiro fault, which bounds its western flank, cuts and deforms a late-kinematic granodiorite massif with a Rb-Sr age of 286 ± 6 Ma (Román-Berdiel et al., 1995; Ortega et al., 2000), which belongs to the same series as others dated by U-Pb at ca. 295 Ma (Fernández-Suárez et al., 2000a). Late development of the Lugo dome was probably a consequence of migration of the extension to the external zones of the orogen with time (Fig. 5), in the same way that compressional episodes D_1 and D_2 had done before, as shown by the diachronous character of their associated cleavages (Dallmeyer et al., 1997).

The amount of extension undergone by the orogenic crust is difficult to estimate, but it seems to be very important given the abundance of extensional detachments and the high strains associated with them and the accompanying regional fabrics. Consequently, the apparently huge displacement shown by the main Variscan thrusts in the allochthonous terranes, including ~200 km for the lower allochthon thrust, may to a large extent be a consequence of late orogenic extension and would have been originally much less (Fig. 5).

GLOBAL VIEW: THE THIRD AND FOURTH DIMENSIONS

The Pieces of the Puzzle

Iberian geology can be correlated with that of central Europe by comparing its stratigraphic, metamorphic, and magmatic features with those of the different zones of the European massifs. The zoning of the Variscan belt was first established in central Europe by Kossmat (1927), and in Iberia by Lotze (1945), and correlations are being continuously updated as more information becomes available (Bard et al., 1971; Julivert et al., 1972; Tollman, 1982; Franke, 1989; Martínez Catalán, 1990; Matte, 2002).

In Figure 2, a correlation has been attempted using a few simple criteria. The autochthonous Central Iberian zone can be compared with the central domain of the Armorican Massif in France based on continuity across the Iberian-Armorican arc and strong stratigraphic similarities (Robardet et al., 1990; Young, 1990). The Ossa-Morena zone of southern Iberia is usually correlated with the northern domain of the Armorican Massif based on the presence of a strong Cadomian imprint and also on stratigraphic grounds (Cogné, 1974; Eguíluz et al., 1984, 2000; Chantraine et al., 1994). It is important to note that the sedimentary and faunal records in Iberia indicate that these zones were part of the northern Gondwanan shelf, distal in the case of the Ossa-Morena zone and proximal in the case of the Central Iberian zone (Robardet and Gutiérrez-Marco, 2004).

The correlation can be continued to the Bohemian Massif based on the presence of Cadomian crust in the Mid-German crystalline zone and the Saxo-Thuringian zone, and also based on the presence of a Cambrian-Ordovician rift sequence in the latter, which shows a stronger similarity to the Central Iberian zone than to the Ossa-Morena zone (Franke, 1989, 2000; Linnemann and Romer, 2002; Linnemann et al., 2003; Robardet and Gutiérrez-Marco, 2004). The Teplá-Barrandian zone has also evident affinities with the autochthonous terranes of northern Gondwana (Franke, 2000), and it includes some of the best-preserved Cadomian basement in Europe. This fact and the Paleozoic succession and faunal similarities (Gutiérrez-Marco et al., 1999, 2001) suggest a connection with the Iberian Ossa-Morena zone or with a zone transitional between the Ossa-Morena zone and the Central Iberian zone.

Exotic terranes with Paleozoic ophiolites, remnants of Cambrian-Ordovician volcanic arcs, and early Variscan high-*P* metamorphism similar in age and evolution to the northwestern Iberian terranes exist along the whole length of the Variscan belt (Fig. 2). They occur in the southern domain of the Armorican Massif (Hanmer, 1977; Marchand, 1981; Balé and Brun, 1986; Ballèvre et al., 1994), in the French Massif Central (Burg and Matte, 1978; Girardeau et al., 1994; Ledru et al., 1994a, 1994b), the Vosges and Black Forest massifs (Wimmenauer and Lim, 1988; Eisbacher et al., 1989; Franke, 1989, 2000), the Saxo-Thuringian and Moldanubian zones of the Bohemian Massif (Tollman, 1982; Behr et al., 1982, 1984; Franke, 1989, 2000; Crowley et al., 2002), and the Polish Sudetes (O'Brien et al., 1997; Kröner and Hegner, 1998; Timmermann et al., 2000; Aleksandrowski and Mazur, 2002; Floyd et al., 2002). Furthermore, the exotic terranes seem to continue to the south in the External crystalline massifs of the Alps and the Maures Massif in southern France, Corsica, and northern Sardinia (Bourrouilh et al., 1980; Frisch et al., 1984, 1987; Becker et al., 1987; Ménot et al., 1988; Vauchez and Bufalo, 1988; von Raumer and Neubauer, 1993, 1994; von Raumer et al., 2002).

Finally, the Rhenian-Hercynian zone wraps around the other zones and can be traced from the Bohemian Massif to the southern British Isles and to southern Iberia, where it is represented by the South Portuguese zone (Oliveira et al., 1979). The Rhenian-Hercynian zone is an external thrust belt and also a foredeep basin that developed during the Middle Devonian and Carboniferous, possibly on Avalonian crust adjacent to the developing Variscan mountain belt.

The correlation shown in Figure 2 by itself does not provide a straightforward interpretation of the history of terrane evolution, convergence, and collision. One of the most important problems to be solved is the paleoposition and origin of the allochthonous terranes. Considering the paleogeographic continental reconstruction for the late Paleozoic (Fig. 1), the ophiolites of northwest Iberia and similar units in central Europe seem to witness an oceanic realm between Gondwana, represented by the autochthon, and Avalonia, represented by the London-Brabant Massif and the eastern Appalachians (Rast and Skehan, 1983; Williams and Hatcher, 1983).

According to current reconstructions (Scotese, 2001; Winchester et al., 2002), that ocean would have been the Rheic. However, it is unrealistic to postulate that the ca. 500 Ma arc-type magmatism preserved in the upper allochthonous units occurred inside the Rheic Ocean when it was beginning to open. Actually, arc development at that time was widespread in the Iapetus Ocean, on the northern side of Avalonia (van Staal et al., 1998; Winchester et al., 2002; van Staal, 2005). Therefore, correlation of the upper allochthonous units with, for instance, an arc occurring outboard of the Iapetus margin of Avalonia is more reasonable.

These facts can be reconciled if the upper units are remnants of a peri-Gondwanan continental block that was drifting at the same time as Avalonia (Gómez Barreiro et al., 2007) or that was detached from its Iapetus margin. These units would have registered active-margin magmatism and, later, would have docked to Laurussia, facing the Rheic Ocean, with Gondwana at the opposite margin, and without any intervening Avalonian terrane (Fig. 5). This possibility would imply that Avalonia did not form a continuous ribbon between Gondwana and Laurussia, at least, not for its easternmost part. Moreover, it is possible that the unstable ocean that drove the slab rollback that detached the upper allochthonous units from Gondwana was not the Iapetus, but the Tornquist Ocean (Fig. 5).

A major problem in interpreting the Variscan belt is how many peri-Gondwanan terranes were involved and how many oceans developed among them. Some interpretations suggest that nearly every ophiolitic unit represents a suture, so that several microcontinents, arcs, and oceans were involved (Matte, 1986, 1991, 2002; Franke, 1989, 2000; Franke and Zelazniewicz, 2002). However, different ophiolites and associated allochthonous units occur in terranes separated from each other by strike-slip shear zones, which suggests that different possible sutures could in fact be the same, repeated by wrench tectonics. The correlation among the Variscan exotic terranes was explored by Martínez Catalán (1990), who concluded that all of them could be remnants of a single gigantic, tongue-shaped allochthonous sheet and that a single ocean might account for all terranes of oceanic affinity. Although possible on purely geometrical grounds, the tongue shape of the allochthon seems mechanically unreasonable and can be replaced by a rather continuous strip along the northern Gondwana platform if the transpressional character of the orogen is considered.

Strike-Slip Tectonics

One of the clues for any interpretation of the Variscan belt resides in the relationship between northwest Iberia and the Armorican Massif, on both sides of the Iberian-Armorican arc. There is a close stratigraphic similarity between the Central Iberian zone and the central Armorican Massif, which has Ordovician and Devonian sections that are identical in Buçaco (western Portugal) and Crozon (western Armorican Massif; Henry et al., 1974; Paris and Robardet, 1977; Robardet et al., 1990; Young, 1990; Paris, 1998), precluding the possibility that both were separated by an oceanic domain. However, the Central Iberian zone and the central domain of the Armorican Massif lie on different sides of the allochthonous terranes (Fig. 2), suggesting that they were separated by a suture, the Massif Central suture of Matte (1991).

This apparent contradiction may be solved from an Iberian perspective. In the southern Armorican Massif, the allochthonous terranes occur adjacent to the southern branch of the South Armorican shear zone, which is considered to overprint the root there (Ballèvre et al., 1994). However, in Iberia, the allochthonous terranes overlie the Central Iberian zone, and their root zone lies outside, to the north, west, or south of the Central Iberian zone. It seems reasonable that the Armorican terranes are also allochthonous and do not root in the southern domain of the massif, in spite of the fact that they seem to root there because they have been overprinted and masked by subvertical shear zones. Therefore, the suture would be rootless in both domains, and the present terrane distribution may be a consequence of wrench tectonics.

Shelley and Bossière (2000, 2002) developed the hypothesis that the terrane collage was essentially due to dextral transpression induced by sliding of Laurentia along the northern margin of Gondwana. Their interpretation relies largely on continental reconstructions by Dalziel et al. (1994) and Dalziel (1997), and in well-established evidence for pervasive Devonian-Carboniferous dextral shearing in the Variscan-Appalachian belt (Gates et al., 1986; Rolet et al., 1994; van Staal and De Roo, 1995; Franke and Zelazniewicz, 2002; Hatcher, 2002).

Shelley and Bossière were right in stressing the importance of strike-slip motion, but paid little attention to the orthogonal component of convergence. However, the importance of orthogonal components is suggested by the subduction and subsequent exhumation of high-*P* allochthonous units and by the large displacement of allochthonous terranes in northwest Iberia and in the Bohemian Massif. Figure 6 is a simplified attempt to incorporate both orthogonal and transcurrent components into a model for the development of the Variscides in a way that is geometrically feasible. It avoids the need to invoke "extra" peri-Gondwanan terranes and intervening oceans.

Our foundations are the tectonic evolution of northwestern Iberia, the evidence that its section is retrodeformable, and the fact that the allochthonous terranes in the Galicia-Trás-os-Montes zone contain a rootless suture.

Both the Galicia-Trás-os-Montes zone and the Central Iberian zone are truncated to the west by the Porto-Tomar dextral shear zone (Ribeiro et al., 1980), which continues into the South Armorican shear zone (Fig. 2). The Galicia-Trás-os-Montes zone might root at a possible cryptic suture at the boundary between the Central Iberian zone and the Ossa-Morena zone, or farther south, between the latter and the South Portuguese zone, where a true suture exists.

The first possibility was explored by Simancas et al. (2002), and it is supported by the presence of a unit comparable to the basal units of the Galicia-Trás-os-Montes zone in the Badajoz-Córdoba sinistral shear zone, which represents the Central Iberian zone–Ossa-Morena zone boundary. However, no ophiolites have been found here, and it is not clear whether these units actually root there or are a narrow klippe pinched at the Badajoz-Córdoba sinistral shear zone. Furthermore, the existence of an oceanic domain between the Central Iberian zone and the Ossa-Morena zone in the Paleozoic is not favored by faunal studies (Robardet, 2002, 2003; Robardet and Gutiérrez-Marco, 2004).

Conversely, ophiolites occur in the Beja-Acebuches ophiolitic complex, at the Ossa-Morena zone–South Portuguese zone boundary (Crespo-Blanc, 1991; Fonseca and Ribeiro, 1993; Quesada et al., 1994; Figueiras et al., 2002). The age of these ophiolites is unknown, but their position in the Variscan belt is similar to those of Lizard in south Cornwall (Fig. 2), dated at 390–400 Ma (U-Pb; Clark et al., 1998; Nutman et al., 2001), so that the Beja-Acebuches ophiolitic complex may be coeval with and perhaps linked to the upper ophiolites of the Galicia-Trás-os-Montes zone, dated at 395 Ma (see also Sánchez Martínez et al., this volume).

Vergences are opposite in the Beja-Acebuches ophiolitic complex suture and the Galicia-Trás-os-Montes zone allochthonous terranes: while emplacement of the Galicia-Trás-os-Montes zone has an eastward component in present coordinates, the recumbent folds and thrusts in the South Portuguese zone, Beja-Acebuches ophiolitic complex, and Ossa-Morena zone show a southwest-directed motion (Silva et al., 1990; Crespo Blanc, 1991; Onézime et al., 2002; Expósito et al., 2002, 2003; Simancas, 2004). This does not necessarily imply that both sutures represent two different oceans, as the opposite vergences may indicate a change in subduction polarity along the plate boundary of a single ocean.

Faunal evidence indicates that the Central Iberian zone and the Ossa-Morena zone were never separated from each other by an ocean during the Paleozoic (Robardet, 2002, 2003; Robardet and Gutiérrez-Marco, 2004), and we assume that both the Beja-Acebuches ophiolitic complex and the Galicia-Trás-os-Montes zone sutures represent the closure of the Rheic Ocean by collision between Gondwana and Laurussia. However, the evolution of each suture was very different. To the east, closure of the Rheic Ocean built an accretionary wedge in the active Laurussia margin, which was later emplaced as a gigantic thrust over the northern Gondwana continental platform (Figs. 5 and 6).

To the west, south-directed subduction of oceanic lithosphere created the Rhenian-Hercynian zone (Kossmat, 1927), where an accretionary wedge developed locally during the Early to Middle Devonian (Silva et al., 1990; Eden and Andrews, 1990; Onézime et al., 2002). Afterward, terrigenous sediments and volcanics were deposited in a foredeep basin during the Late Devonian to Middle Carboniferous (Oliveira, 1990), and they deformed closely following deposition, forming a thin-skinned thrust belt (Franke, 2000; Oncken et al., 2000; Onézime et al., 2002). A transform fault might have separated the two parts of the Laurussia-Gondwana plate boundary with opposite subduction polarities.

We begin our cartoon (Fig. 6) at the Early Carboniferous, when the Rheic Ocean had been closed, the northern Gondwana

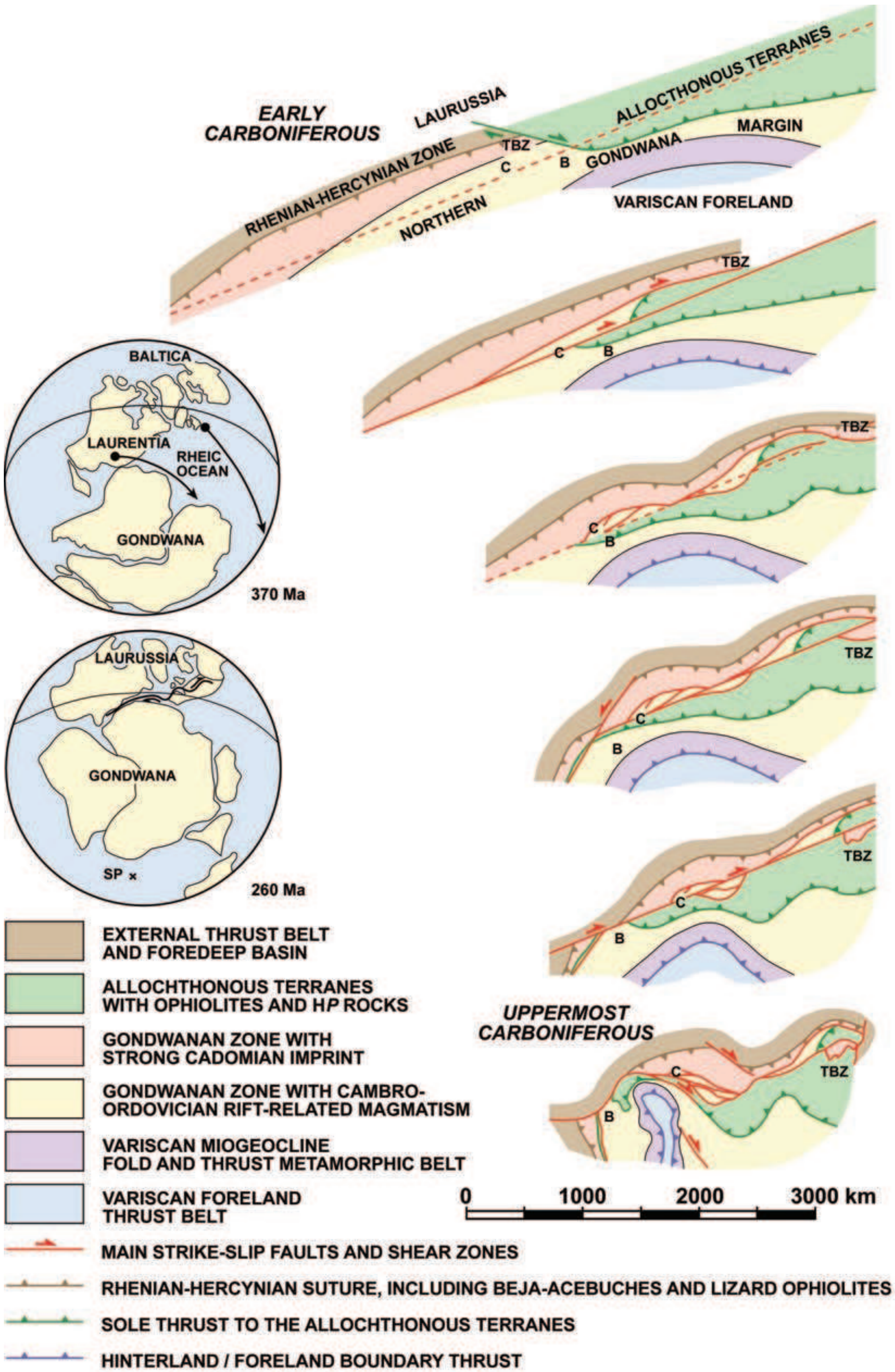

Figure 6. Map view of the proposed evolution of the Variscan belt during the Early and Middle Carboniferous, explaining the different allochthonous terranes as remnants of a huge nappe stack thrust onto the northern platform of Gondwana. Compare with Figure 2 to locate the main massifs and zones and their evolution during strike-slip motion. Note in particular the original neighborhood of Buçaco (B), Crozon (C), and the Teplá-Barrandian zone (TBZ), characterized by similar Paleozoic successions and closely related faunal assemblages. The inset shows the clockwise rotation of Laurentia and Baltica, which provided the convergent component of transpression, and the Carboniferous dextral shearing along the northern margin of Gondwana (after Shelley and Bossière, 2002).

platform had recorded the early deformation events related to collision, and the allochthonous terranes, including ophiolites and previously subducted rocks, had been obducted onto it. The complexities of this stage were described in a previous section and are sketched in Figure 5. The Rhenian-Hercynian basin had developed already and was the site of synorogenic sedimentation and deformation. This is the starting point of our model in the third dimension, which explains how the allochthonous terranes and the Gondwanan autochthon became subsequently dismembered by strike-slip shear zones and faults that produced ~3000 km of dextral displacement, and how the Rhenian-Hercynian zone came to be placed to the north of the allochthonous terranes, duplicating the Rheic suture and producing the double vergence characteristic of the Variscan belt.

Probably, wrench components did not appear then for the first time. In fact, dextral transpression has been identified in the Appalachians since the Early Devonian (van Staal and De Roo, 1995), and Late Devonian–Early Carboniferous dextral displacements have been suggested for the central European Variscides by Franke (2000) and for the Armorican Massif by Rolet (1994). It is possible that oblique convergence was active from the beginning of the Variscan cycle, when the Rheic Ocean began to close, and it may have been responsible for the orogen-parallel stretching lineations so common in many allochthonous units (Burg, 1981; Quinquis and Choukroune, 1981; Vauchez and Bufalo, 1988; Ribeiro et al., 1990; Llana-Fúnez, 2002).

The Iberian-Armorican arc has been interpreted as an oroclinal bend that developed from rigid-plastic indentation during collision (Matte, 1986). The arc is rather tight when considering its inner zones, which have a paleogeographic significance (Lotze, 1945; Julivert et al., 1972, 1980). Conversely, it is more open when affecting the main dextral wrench system (Porto-Tomar dextral shear zone–South Armorican shear zone). Even admitting the existence of a primary open arcuate structure, as indicated by paleomagnetism (Perroud and Bonhommet, 1981; Perroud, 1982; Hirt et al., 1992), Figure 2 suggests that oroclinal bending was coeval with late orogenic stages, and also with the concomitant wrenching. This may explain the sinistral motion of shear zones, which limited the Ossa-Morena zone in the southern branch of the arc, and the formation of fan imbricates and strike-slip duplexes such as those apparently present in the Armorican Massif, which could have formed by the master fault cutting across oroclinal bends (Fig. 6).

The timing of the different steps of the proposed sequence remains imprecise, but the strike-slip activity is bracketed between 345 and 300 Ma, the interval of motion of dextral shear zones in the Armorican Massif (Diot et al., 1983; Peucat et al., 1984; Rolet, 1994), which is similar to ages in Iberia, including 342 Ma amphibolite-facies deformation in the Beja-Acebuches ophiolitic complex (^{40}Ar/^{39}Ar age; Dallmeyer et al., 1993). It is coeval with or predates sinistral movement, dated at 315–305 Ma for the Porto-Tomar and Juzbado-Penalva shear zones (Rb-Sr ages, Regêncio Macedo, 1988; U-Pb ages, Valle Aguado et al., 2005).

When comparing cross-section and map-view evolution, it is clear that orthogonal shortening and strike slip were active during most of the Carboniferous. This may explain repeated thrusting in northwest Iberia (Fig. 5) and perhaps northwest-directed thrusting of the allochthonous terranes in the Bohemian Massif (Franke, 1989, 2000; Collins et al., 2000). Thrust tectonics reflect the orthogonal component of transpression and tend to hide or delete the traces of previous along-strike components (Johnston, 2001). Therefore, well-preserved strike-slip structures are those formed after thrust and nappe tectonics have ceased in a region. Both orogenic mechanisms reflect a partition of deformation during oblique convergence and may act at the same time, and northwest Iberia is a clear example of such behavior: the Porto-Tomar and Juzbado-Penalva shear zones (Fig. 2) moved between 315 and 305 Ma (Regêncio Macedo, 1988; Valle Aguado et al., 2005), when thin-skinned tectonics were active in the Cantabrian zone (Fig. 5).

CONCLUSIONS

The northwestern Iberian Massif offers a clue to understanding the evolution of the Variscan belt, mainly because strike-slip structures are subordinate inside the section, which makes it retrodeformable. A key aspect of the section is the presence of exotic terranes that form a huge and complex allochthonous sheet emplaced upon the sequences deposited on the passive margin of northern Gondwana. The geochemistry of igneous rocks and isotopic age data show that the exotic terranes include parts of a peri-Gondwanan terrane that evolved as a Late Cambrian–Early Ordovician island arc, suprasubduction ophiolites, and pieces of the outermost edge of the Gondwanan continental margin. A precise matching between the ages of metamorphic fabrics and development of large structures has been attempted and the structures have been interpreted in the context of a two-stage evolutionary model consisting of an early Variscan accretionary stage, related to the closure of the Rheic Ocean, followed by a Variscan collisional stage.

Correlation of Iberian allochthonous terranes with those in central European massifs, and also of strike-slip structures along the Variscan belt, have resulted in the elaboration of a transpressional tectonic model for the Variscides that avoids the multiplication of microcontinents and narrow oceanic domains. The model explains the whole belt in terms of the closure of a single ocean, the Rheic, and the subsequent oblique collision between Gondwana and Laurussia. Overprint of a gigantic allochthonous sheet by strike-slip shear zones and faults with a total displacement of ~3000 km may account for the apparent multiplicity of sutures and peri-Gondwanan terranes.

Given the importance of dextral transpression in the Variscan-Appalachian belt, the paleoposition of Iberia along the Gondwanan margin might have been more to the east than suggested by late Paleozoic reconstructions. It is possible that northwest Iberia faced the Tornquist Ocean during the early Paleozoic, that early Variscan deformation was a consequence of Gondwana-Baltica convergence, and that the early Variscan accretionary prism preserved in the allochthonous terranes developed in the southern margin of Baltica.

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