A two-stage collision at the origin of Pangea: the allochthonous Variscan terranes

Dos episodios de colisión en el origen de Pangea: los terrenos alóctonos Variscos

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Abstract: The Variscan suture exposed in NW Iberia contains two allochthonous terranes with Gondwanan provenance (upper and basal units), separated by ophiolites with protolith ages at c. 395 Ma. The tectonothermal evolution of the continental terranes records two consecutive events of deep subduction. The upper units record an initial high-P/ultra-high-P metamorphic event that occurred before 400-390 Ma, while the basal units were affected by a second high-P/low-to-intermediate-T metamorphic event at c. 370 Ma. Repeated continental subduction affecting the most external margin of Gondwana occurred in a setting of dextral convergence with Laurussia. The two high-P events alternated with the opening of an ephemeral oceanic basin, probably of pull-apart type, in Early Devonian times. This ephemeral oceanic domain is suggested as the setting for the protoliths of the most common ophiolites involved in the Variscan Orogen. Current ideas for the assembly of Pangea advocate a single collisional event in Carboniferous times. However, the new evidence from the allochthonous terranes of the Variscan Orogen suggest a more complex scenario for the assembly of the supercontinent, with an interaction between the colliding continental margins that started earlier and lasted longer than previously considered.

Key words: Assembly of Pangea, Allochthonous Variscan terranes, NW Iberian Massif.

Resumen: *La sutura Varisca del NW de Iberia contiene dos terrenos alóctonos con procedencia Gondwánica (unidades superiores y basales), separadas por ofiolitas con protolitos datados en c. 395 Ma. La evolución tectonotermal de los terrenos continentales registra dos eventos consecutivos de subducción profunda. Las unidades superiores registran un evento inicial de metamorfismo de alta/ultra- alta-P que tuvo lugar antes de 400-390 Ma, mientras que las unidades basales muestran un segundo metamorfismo de alta-P y baja-intermedia-T datado en c. 370 Ma. La subducción continental repetida del margen externo de Gondwana tuvo lugar durante convergencia dextra con Laurussia. Los eventos de alta-P alternaron con la apertura de una cuenca efímera, probablemente de tipo pull-apart, durante el Devónico Inferior. Se interpreta que en este dominio oceánico efímero se generaron los protolitos de las ofiolitas más comunes del Orógeno Varisco. Las ideas más habituales sobre el ensamblado de Pangea consideran una colisión simple durante el Carbonífero. Sin embargo, las nuevas evidencias obtenidas en los terrenos alóctonos del Orógeno Varisco sugieren un escenario más complejo para el ensamblado del supercontinente, con una interacción entre los márgenes continentales colisionantes que comenzó antes y duró más de lo inicialmente considerado.*

Palabras clave: *Ensamblado de Pangea, Terrenos alóctonos Variscos, NW del Macizo Ibérico.*

INTRODUCTION

It is broadly accepted that the assembly of Pangea occurred in Carboniferous and Early Permian times, after a long stage of continental convergence that ended with the closure of the Rheic Ocean and the collision of Gondwana and Laurussia (e.g. Nance et al., 2010). In the Variscan Orogen, the oldest tectonothermal events are preserved in a complex suture zone that can be traced from the Iberian Peninsula to the Bohemian Massif. The suture zone is made up of a stack of allochthonous terranes with ophiolites and high-P (HP) and ultra-high-P (UHP) metamorphic rocks. One of the most distinctive features of the Variscan Orogen is the presence of two different events of HP metamorphism that appear to have occurred relatively close in time, but were separated by the development of oceanic basins. This evolution is unusual in large collisional belts, whose tectonothermal evolution is commonly interpreted as reflecting a single HP or UHP metamorphic event associated with subduction of one of the colliding continental margins. In the Variscan Orogen, both HP events and the development of some of the oceanic domains occurred after the earliest Devonian and are thus broadly coeval with the initial stages of the assembly of Pangea.

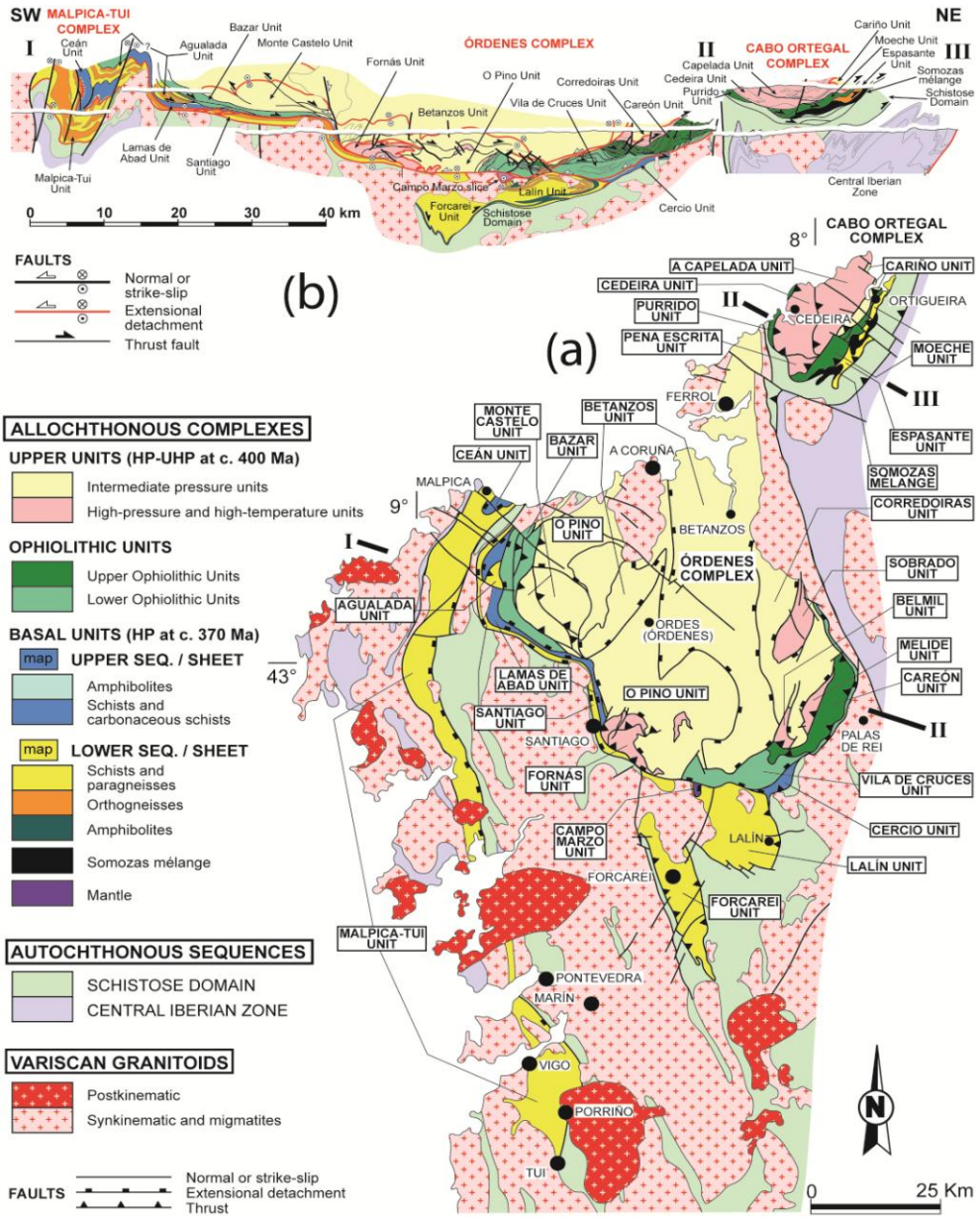

FIGURE 1. *(a) Geological map of the allochthonous complexes of the NW Iberian Massif (Galicia region); (b) Composite cross section, showing the distribution and general structure of the terranes involved in the Variscan suture.*

TERRANES IN THE VARISCAN SUTURE

The NW Iberian section of the Variscan Orogen contains different terranes with contrasting origins and tectonothermal evolution. The Central Iberian Zone represents the lowest sequence and together with a parautochthonous domain (or Schistose Domain) defines the main section of the Gondwanan margin involved in the Variscan Orogen (Fig. 1). On top, a set of allochthonous terranes of alleged exotic nature forms a nappe stack representative of the suture zone (Fig. 1). Three main groups of terranes have been identified, two of which show continental crustal affinities (basal and upper units). These are separated by ophiolites representing the suture itself (ophiolitic units, Fig. 1).

Located immediately below the suture, the basal units contain metasedimentary rocks (Ediacaran to Early Ordovician), calc-alkaline to alkaline-peralkaline metagranitoids, and some mafic rocks. The basal units are considered to represent a section of the most external margin of Gondwana located somewhere between the West African and Saharan cratons (Díez Fernández et al., 2010). The first tectonothermal event recorded in these units is a HP and low- to intermediate-T (LIT) event dated at c. 370 Ma (Abati et al., 2010). A variety of HP mica schists and orthogneisses, C-type eclogites and some blueschists were formed at this time.

Resting on top of the suture zone, the upper units consist of a pile, 10–12 km thick, of metasedimentary rocks (mainly Cambrian metagreywackes), large massifs of calc-alkaline orthogneisses, and gabbros with compositions of island-arc tholeiites, together with medium to high grade mafic rocks, including B-type eclogites and HP granulites, and some ultramafic massifs. These units were part of a Cambrian peri-Gondwanan magmatic arc, and were located west of the external margin section represented by the basal units (Díez Fernández et al., 2010; Albert et al., 2015). The upper units may be divided into two groups according to metamorphic criteria: an uppermost section with intermediate-P metamorphism ranging from the chlorite zone to the granulite facies, and a lower section showing HP-UHP and high-T (HT) metamorphism dated at c. 400-390 Ma (Fernández-Suárez et al., 2007). The main tectonothermal events recorded in the uppermost section are Cambrian in age and were probably developed in response to the accretionary dynamics of the peri-Gondwanan arc system (Abati et al., 1999).

Two groups of ophiolitic units have been distinguished (Fig. 1): an older group (lower ophiolitic units) containing metaigneous rocks of Late Cambrian age (c. 497-495 Ma), and a younger group (upper ophiolitic units) including gabbroic rocks of Devonian age (Emsian-Eifelian; c. 395 Ma) (e.g. Arenas and Sánchez Martínez, 2015). The lower ophiolitic units are interpreted to represent a series of mafic complexes linked to the dynamics affecting the most external margin of Gondwana in Cambrian–Early Ordovician times. The Middle Devonian ophiolites are the most abundant group found in the Variscan suture. A combined isotopic (Lu-Hf in zircon and Sm-Nd in whole rock) study of these ophiolites shows that a suite of Devonian gabbros with juvenile isotopic compositions and mantle provenance (the mafic protoliths of the ophiolites) interacted with old continental crust and were affected by limited mixing (e.g. Arenas and Sánchez Martínez, 2015). The involvement of a continental component is revealed by Paleoproterozoic Hf model ages in some of the zircons, which is inconsistent with the generation of the igneous protoliths in an intra-oceanic setting located far away from continents.

A TWO-STAGE COLLISION MODEL FOR THE EARLY HISTORY OF PANGEA

The new data from the allochthonous terranes of NW Iberia seem to be consistent with the development of two successive collision events between Gondwana and Laurussia, each taking place in a context of oblique convergence and separated in time by the opening of a rather wide oceanic basin, probably of pull-apart type.

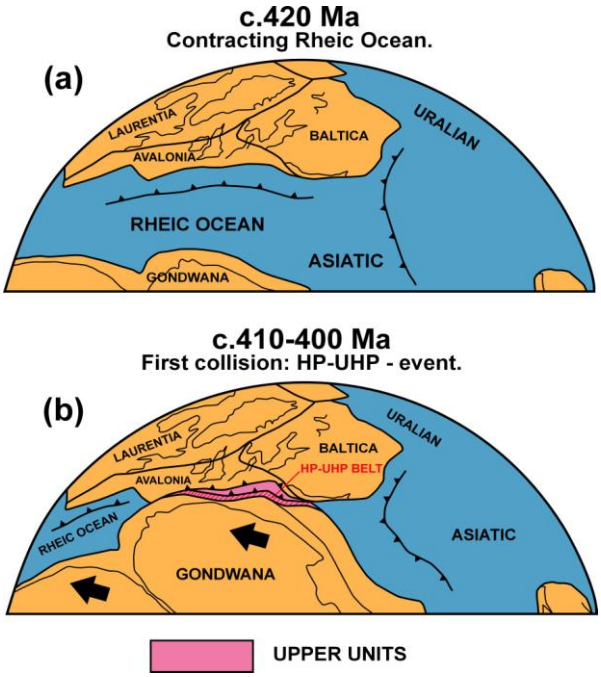

FIGURE. 2. *Reconstructions of: (a) The Rheic Ocean realm at the Silurian–Devonian boundary; (b) The initial collision between Gondwana and Laurussia at c. 410-400 Ma, following the complete closure of the Rheic Ocean.*

The allochthonous upper units are interpreted as the most external part of the Gondwanan margin, a rather wide continental shelf containing thick turbidite series intruded by large massifs of gabbros and granitoids. This lithological succession was formed during the activity of a volcanic arc in Cambrian times. This continental shelf did not witness significant new igneous activity or deformation until the onset of the HP–UHP metamorphic event, and hence it shows the characteristics of a typical passive margin for most of the Ordovician and Silurian. In the geological record covering this time interval there is no evidence suggesting any significant separation of this continental shelf from the Gondwanan mainland. Convergence between Gondwana and Laurussia led to a first continental collision before 400-390 Ma, including the dextral subduction of the most external and thinned part of the Gondwanan margin to the north accompanied by the first HP–UHP metamorphism. The southern margin of Laurussia acted as the upper plate in the subduction complex and the most important collision probably affected the eastern part of Avalonia and the Baltic margin (Fig. 2).

Renewed dextral motion between Gondwana and Laurussia favored the rapid generation of a rather wide pull-apart basin in Early Devonian times, which we interpret as the tectonic setting for the generation of the c. 395 Ma mafic rocks forming the most typical ophiolites involved in the Variscan suture (Fig. 3). The continued dextral convergence finally caused the closure of the pull-apart basin and the accretion of

buoyant oceanic lithosphere beneath the northern continent starting at c. 380 Ma (Careón and Purrido ophiolites). The accreted oceanic lithosphere is mostly metamorphosed to the amphibolite facies. Later accretion of new Devonian mafic slices took place under greenschist facies conditions (Moeche Ophiolite), and was followed by the accretion of mafic complexes rimming the continental margin that was formed within the Cambrian peri-Gondwanan volcanic arc (Vila de Cruces Ophiolite). The final outcome was the generation of a complex suture zone that records protracted dextral convergence and is characterized by the presence of a double ophiolitic belt of contrasting origin and ages: the upper ophiolitic units of Devonian age and the lower ophiolitic units of Cambrian age.

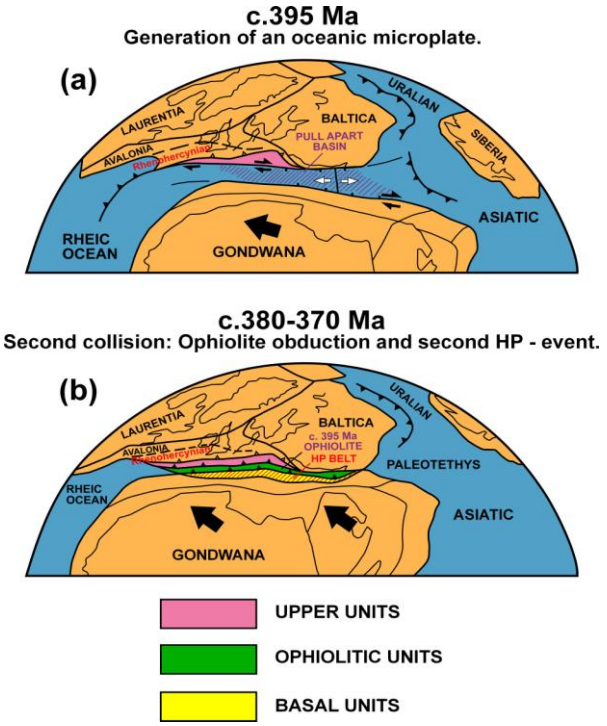

FIGURE. 3. *Reconstructions showing: (a) Dextral motion between Gondwana and Laurussia, which favored the opening of a rather ephemeral pull-apart basin at c. 395 Ma; (b) The second and final collision at c. 380-370 Ma, developing a second HP–LIT metamorphic belt.*

The final collision between Gondwana and Laurussia started at c. 370 Ma as a consequence of continued oblique dextral convergence. It caused renewed north-directed subduction affecting a new section of the external Gondwanan margin with a more easterly provenance (basal units; Díez Fernández et al., 2010; Díez Fernández and Arenas, 2015). This is the suggested setting for the development of the second HP metamorphic event, formed under LIT conditions and generating C-type eclogites, blueschists and HP metapelites (Fig. 3). Convergence continued for about 70 m.y. as intracontinental deformation progressed southward, reaching inner sections of Gondwana while building a foreland fold and thrust belt in the external parts of the orogen.

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