Oroclines of the Iberian Variscan belt: Paleocurrent analysis, U-Pb detrital zircon age dating, and paleogeographic implications

Oroclinales del orógeno Varisco Ibérico: Análisis de paleocorrientes, edades U-Pb de circones detríticos e implicaciones paleogeográficas

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Abstract: Paleocurrent and U-Pb detrital zircon age data from the Lower Ordovician Armorican Quartzite of the Cantabrian, West Asturian-Leonese and Central Iberian zones define the geometry and paleogeography of the Iberian Variscan belt. Paleoflow directions oriented at high angles to structural strike reveal the Cantabrian Orocline of northwest Iberia to be continuous with a second, the Central Iberian Orocline. The two oroclines form an s-shaped fold pair of continental scale. Palinspastic restoration to a paleomagnetically constrained Late Variscan (Carboniferous) N-S trend yields a linear orogenic ribbon (The Cantabrian – Central Iberian Ribbon) >1500 km long characterized by passive margin strata (presumably Gondwanan) that display an offshore paleoflow towards a westerly oceanic domain (presumably the Rheic). Detrital zircons suggests that the Cantabrian-Central Iberian ribbon formed part of the L. Paleozoic Gondwanan margin that stretched east-west along the northern limits of the Saharan Metacraton and Arabian-Nubian Shield. A 90° counterclockwise rotation is required to reorient the ribbon to an Early Variscan N-S trend, suggesting post-Lower Ordovician, pre-Variscan separation from Gondwana.

Keywords: Oroclines, Armorican quartzite, paleocurrent, detrital zircons, Variscan paleogeography.

Resumen: *Datos de paleocorrientes y edades U-Pb de circones detríticos en la Cuarcita Armoricana, (Ordovícico Inferior) en las Zonas Cantábrica, Asturoccidental-Leonesa y Centroibérica definen la paleogeografía del Orógeno Varisco Ibérico. Las direcciones de paleocorrientes son ortogonales a las de las estructuras, y revelan la existencia del Oroclinal Cantábrico en el NW de Iberia que se continúa más al Sur en el Oroclinal Centroibérico. Ambos oroclinales trazan un gran pliegue con forma de "s" a escala continental. La restauración palinspástica, de acuerdo con los criterios paleomagnéticos existentes, resulta en un cinturón orogénico con una orientación N-S de más de 1500 km de longitud en el Carbonífero. Este margen pasivo (gondwánico) muestra un paleoflujo en dirección a un dominio oceánico situado al oeste (el océano Réico). Los datos de procedencia de circones detríticos de la Cuarcita Armoricana sugieren que el cinturón Cantábrico-Centroibérico formaba parte en el Paleozoico Inferior del margen pasivo de Gondwana situado en torno de los cratones Sahariano y Arábigo-Nubio con una orientación E-W. Estos datos sugieren una rotación antihoraria de 90º y una separación de este margen de Gondwana antes de la colisión Varisca.*

Palabras clave: *Oroclinal, cuarcita Armoricana, paleocorriente, circones detríticos, paleogeografía Varisca*

INTRODUCTION

Coupled paleomagnetic and structural analyses have shown that the 180° bend that defines the of the Cantabrian Orocline of the Iberian Variscan Orogen developed by vertical axis rotation of an originally north-south trending linear orogen in the Upper Carboniferous – lowermost Permian (e.g. Weil et al., 2010). The Variscan provides the European record of Paleozoic continental collisions that culminated in the formation of Pangea. Understanding the Variscan is therefore critical to constructing robust geodynamic and tectonic models for supercontinent formation. Constraining the paleogeography of the Iberian Variscan orogen is complicated by contrasting sedimentary provenance within 'autochthonous' portions of the orogen, and by difficulties in palinspastic restoration owing to (1) an unusually great orogenic width (>700 km), (2) exposures of shallow water Gondwana margin strata in the northern and southern portions of the orogen, and (3) inexposure of a Paleozoic continental sedimentary source. Du Toit

(1937), described the Variscan Orogen as being 'constituted by a series of interlinked wide arcs', and depicted the Variscan of Iberia as being characterized by two bends. The first, (what we now know as the Cantabrian Orocline) northerly and concave eastward towards the foreland. The second, southerly, concave westward towards the hinterland, and linked into the Cantabrian Orocline through the NNW-SSE trending Iberian Cordillera. The idea of a southern bend in the Variscan has been recently revisited by Aerden (2004) and Martínez Catalán (2011) and may hold the key to resolving at least some of these outstanding problems. We present paleocurrent and detrital zircon data from Lower Ordovician siliciclastic sedimentary rocks (the Armorican Quartzite) sampled across northern and central Iberia in order to (1) test for the presence of a second, Central Iberian bend, and (2) further constrain palinspastic restoration and paleogeography of the Iberian Variscan Orogen.

PALEOCURRENT DATA AND IMPLIED IBERIAN GEOMETRY

Paleocurrent data were collected from over 50 sites spread across the Cantabrian, WAL and CI zones of the Iberian Massif and the WALZ correlative Iberian Range. Rose diagrams constructed following structural analysis and bedding restoration are keyed by current indicator type and scaled by dataset size in order to visually convey comparative robustness. A plot by location (Fig. 1) shows current fanning outward from the foreland core of the Cantabrian Orocline. Consistent with the pattern in the north, dominant current runs perpendicular to structural trend throughout the peninsula. The implication of paleocurrents being perpendicular to structural strike and outward from the Cantabrian foreland, is that (moving clockwise from the northwest) flow direction transitions from southward in the WNW-ESE trending structures of the CZ, WALZ and northern CIZ through westerly in the NNW-SSE trending Iberian Cordillera and eastern Spanish Central System (sites 8,9), and through a northwesterly direction reflective of northward structural deflections in the easternmost southern CIZ (Sites 15, 19) to ultimately reach consistently north to northeasterly directions in the WNW-ESE striking southern CIZ (sites 11-14, 16, 17).

Fanning of paleocurrent direction around the Cantabrian Orocline is attributable to bending of a formerly N-S trending linear orogen, palinspastic restoration of which yields a consistent westward paleocurrent direction implying an oceanward direction to the west and a landward direction to the east. As predicted by Du Toit (1937), changes in paleocurrent direction documented across the Iberian Peninsula argue for a second, more southerly bend that is continuous with, but convex in the opposite direction of the Cantabrian Orocline. The presence of a southern bend (the Central Iberian) explains the widespread occurrence of shallow water strata, and faunal and sedimentary data from southern Iberia that imply a

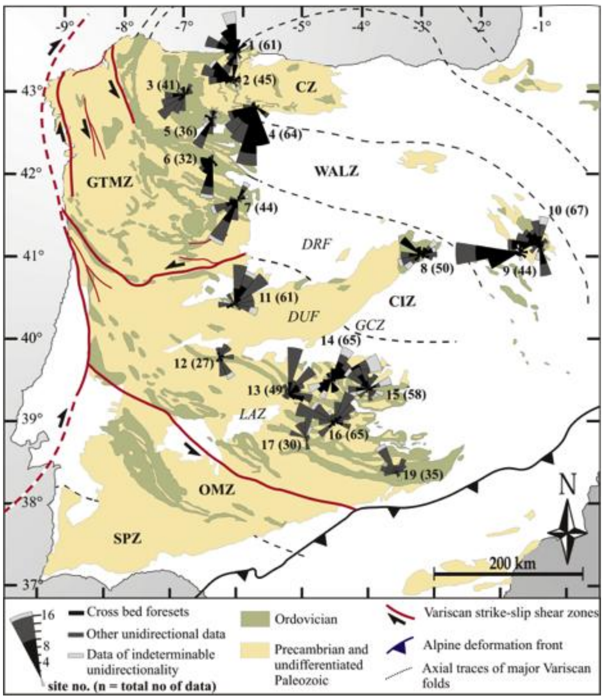

FIGURE 1. *Paleocurrent data from Lower Ordovician rocks of the Iberian Peninsula. Orogenic curvature is highlighted by fanning paleocurrent roses, keyed by current indicator type and scaled according to dataset size. Dashed lines are inferred tectonostratigraphic zone boundaries. From Shaw et al. (2012).*

northward oceanward direction (eg. Robardet, 2002). Formation of the southern bend in the same fashion and at the same time as the northern orocline is suggested by (1) continuity of structures and strata around the two bends, (2) the similarity of structural style between them and (3) a constant and predictable relationship of relative porphyroblast rotation to the bends (Aerden, 2004). The southern bend is henceforth referred to as the Central Iberian Orocline (Martínez Catalán, 2011). Correlation of rocks along strike around the Central Iberian Orocline implies that the WALZ of northern Iberia is correlative with the Luso-Alcudian domain of the southern CIZ, consistent with metamorphic grade increasing southward in the former and decreasing southward in the latter. Correspondence of the hinge line of the Central Iberian Orocline with the boundary between southerly upright and northerly recumbent structural domains of the CIZ is consistent with (1) geometries established by aeromagnetic anomalies attributable to Varsican rocks buried beneath Mesozoic and younger sedimentary cover (2) deflections in structural trend, (3) distributions of allochthonous terranes, and (4) available paleomagnetic data (Shaw et al., 2012). Together, the Cantabrian and Central Iberian oroclines define an s-shaped fold pair of continental scale. Palinspastic restoration of the fold pair to original N-S trend yields a linear orogenic ribbon (The Cantabrian – Central Iberian Ribbon) >1500 km long and characterized by passive margin strata (presumably Gondwanan) that display a consistent offshore paleoflow towards a westerly oceanic domain (presumably the Rheic).

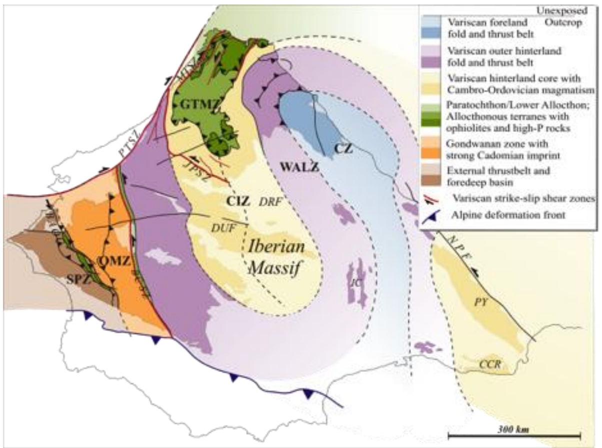

FIGURE 2. *Correlations of tectonostratigraphic zones across the Western European Variscan Belt prior to Cenozoic opening of the Cantabrian Sea (Bay of Biscay) drawn in accordance with the double orocline model for the Variscan belt in Iberia. Tectonostratigraphic zones of southern Iberia. From Shaw et al. (2012).*

DETRITAL ZIRCON DATA: PALEOGEOGRAPHIC IMPLICATION

Detrital zircons ages from nine locations within the Cantabrian, WAL and CI zones were dated using LA-ICP-MS U-Pb techniques. Data are used to (1) assess interpretation of the Cantabrian – Central Iberia Ribbon (CCIR) as having been derived from a linear, N-S striking, west-facing portion of the Gondwana passive margin and (2) constrain the pre-Variscan paleogeography of the Cantabrian–Central Iberian portion of the Gondwana passive margin through sedimentary provenance analysis. Four dominant U-Pb age population groups define a detrital zircon signature common across the studied area. Each sample contains a suite of zircon ages between ca. 550 and 1100 Ma accounting for 70-80% of the total number of concordant grains analyzed per sample. Two statistical peaks within this range, one ca. 700 Ma and one straddling the Neo-Mesoproterozoic boundary at 1.0 Ga, suggest a coalescing of (1) Neoproterozoic (ca. 500-800) and (2) Grenvillian (ca. 0.9-1.1) age populations. Less dominant Paleoproterozoic (ca. 1.8-2.2 Ga) and Archean (ca. 2.5-2.7 Ga) populations have more poorly defined peaks ca. 1.9 and 2.6 Ga, respectively. Insignificant site-to-site variation through widely ranging age groups suggests uniform shelf distribution of a highly varied detrital input along a cohesive portion of the Gondwana passive margin. Consistency with underlying sequences suggests little change in sedimentary provenance from the Neoproterozoic through lower Paleozoic, disqualifies both the West African and Amazonian cratons as likely sources, and provides further elucidation of the provenance distinction within the autochthonous Iberian Massif. This distinction, across the OMZ – CZ boundary, suggests that the OMZ did not form a portion of the CCIR as it is currently defined. An East

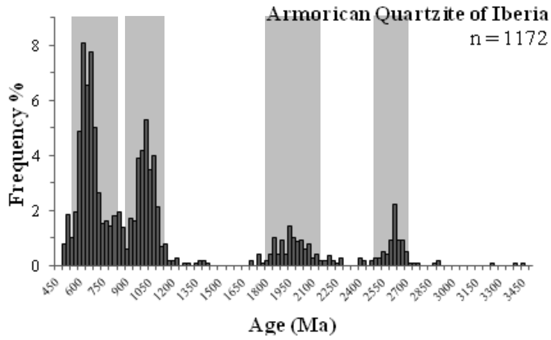

FIGURE 3. *Histogram plot of U-Pb detrital zircon ages for the Armorican Quartzite of the Cantabrian, WAL and CI zones of the Iberian Massif. Ages shown are 90-100% concordant; n = 1172; shaded regions show age populations characteristic for each of the 9 sites included in this histogram.*

African sedimentary affinity is suggested by Ordovician paleontological data (Mélou et al., 1999) and a Western Egyptian Desert crustal source for Central Iberian Cambro-Ordovician magmatism (Bea et al., 2010). The common Armorican Quartzite signature is shared by Cambro-Ordovician clastics from the Saharan Metacraton (Meinhold et al., 2011) and peripheral Arabian-Nubian shield (e.g. Avigad et al., 2003), but inconsistent with the range of basement ages in northeast Africa and Arabia. Hf-isotope data supports long distance sedimentary transport across a northeast African peneplain from basement terranes exposed far to the south (in modern day coordinates) (Morag et al., 2011).

A paleogeographic model in which the CCIR forms a portion of the Lower Paleozoic Gondwana passive margin stretching, in modern day coordinates with the Red Sea closed, along the northern margins of the Saharan Metacraton and Arabian Nubian shield (Fig. 3) satisfies (1) the West Egyptian crustal source of Cambro-Ordovician magmatic rocks documented through Nd T_{DM} model ages by Bea et al. (2010) (2) the similar Ordovician Iberian and Cambro – Ordovician northeast African detrital zircon signatures (3) east African-type fauna observed in Ordovician sequences of the CI and WAL zone. Assuming that stable Africa maintained a similar orientation throughout the Lower to Middle Paleozoic, the suggested paleogeographic location of the CCIR during passive margin sedimentation was along the east to west-striking margin, contrasting the N-S trend paleomagnetically constrained for the Carboniferous. An East-African paleogeographic position during the Lower Ordovician therefore requires a 90 degree counterclockwise rotation that post-dates deposition of the Armorican Quartzite but pre-dates Carboniferous Variscan orogeny.

CONCLUSIONS

The Cantabrian and Central Iberian bends define an s-shaped oroclinal pair in the Iberian Variscan belt. Palinspastic restoration of the fold pair yields and originally linear orogenic ribbon (the Cantabrian–

Central Iberian Ribbon) >1500 km in length. The geometry of the fold pair cannot be defined beyond the limits of the northern and central Iberian Massif; therefore, the palinspastically restored ribbon (and any interpretation of its paleography) must exclude southernmost Iberia (south of the Badajoz–Cordóba shear zone). Based on detrital zircon, paleontological and Nd T_{DM} model aga data, we propose that the ca. 1500 km long CCIR formed a portion of the Early Paleozoic East African Gondwanan margin that was rooted in Western Desert crust and stretched, assuming that Africa has maintained a similar orientation since the Lower Paleozoic, E-W along the northern limits of the then low-lying Saharan Metacraton and Arabian Nubian Shield. A 90° counterclockwise rotation is required to reorient the ribbon to an Early Variscan N-S trend, suggesting post-Lower Ordovician, pre-Variscan (Carboniferous) separation from Gondwana.

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