One or two oroclines in the Variscan orogen of Iberia? Implications for Pangea amalgamation

Daniel Pastor-Galán, Thomas Groenewegen, Daniël Brouwer, Wout Krijgsman, and Mark J. Dekkers
Paleomagnetic Laboratory "Fort Hoofddijk", University of Utrecht, Budapestlaan 17, 3584CD Utrecht, Netherlands

ABSTRACT

The supercontinent Pangea formed in the late Carboniferous as a result of the Gondwana-Laurussia collision, producing the strongly sinuous Variscan–Alleghanian orogen. Iberia is interpreted to comprise two Variscan bends, forming an S-shaped orogenic belt: the Cantabrian orocline to the north and the Central Iberian bend to the south. Coeval formation of both oroclines, however, requires significant north-south shortening (in present-day coordinates) during Pangea's amalgamation. In contrast to the Cantabrian orocline, neither the kinematics nor geometry of the Central Iberian bend is well constrained. We provide paleomagnetic data from the southern limb of the Central Iberian bend, showing ~60° counterclockwise vertical axis rotation during the late Carboniferous to early Permian, comparable to that determined for the southern limb of the Cantabrian orocline. This result is incompatible with the hypothesized S-shaped bend in the Iberian Variscides. We argue that Central Iberia, if really bent, must have acquired its curvature before the Cantabrian orocline, the curvature being an inherited structure. We propose a new mechanism of Pangea formation, compatible with the geology, geochronology, and paleomagnetism, in which a clockwise rotation of Gondwana produces the necessary change in the stress field to form the late Variscan Cantabrian orocline.

INTRODUCTION

The supercontinent Pangea is one of the cornerstones of geology, but the kinematics and mechanisms responsible for its amalgamation are poorly understood and hotly debated. The result is an assortment of models for its assembly (Domeier et al., 2012; Stampfli et al., 2013; Domeier and Torsvik, 2014, and references therein). The general consensus is that Pangea amalgamated during the late Paleozoic from the oblique collision between Gondwana, Laurussia, and several microplates, forming the westward-younging Variscan–Alleghanian orogen (Quesada, 1991; Hatcher, 2002; Nance et al., 2010; Chopin et al., 2014). This orogen has several oroclines, i.e., the Pennsylvanian bend in the American sector, and the Bohemian, Cantabrian, and alleged Central Iberian bends in the European segment (Fig. 1; e.g., Martínez Catalán, 2011).

The formation of oroclines is the process by which an originally roughly linear mountain range bends into a curved configuration (Carey, 1955). Oroclines occur worldwide in orogenic zones of all geologic ages (Rosenbaum, 2014), and their degree of curvature can range from tens of degrees to as much as 180°; they may affect the entire lithosphere (e.g., Pastor-Galán et al., 2012) and can represent up to thousands of kilometers of shortening (Johnston et al., 2013). Incorporating oroclines into tectonic and paleogeographic reconstructions is therefore unavoidable. Surprisingly, most paleogeographic reconstructions of Pangea ignore the role of these Variscan–Alleghanian oroclines, despite the fact that some are kinematically well constrained.

The Cantabrian orocline is one of the best studied oroclines on Earth (e.g., Gutiérrez-Alonso et al., 2012; Weil et al., 2013). Extensive paleomagnetic, geochronological, and structural data constrain its development to the late Carboniferous–early Permian (Moscovian to Asselian, ca. 310–297 Ma; van der Voo et al., 1997; Weil et al., 2010; Pastor-Galán et al., 2011, 2014: Gutiérrez-Alonso et al., 2015), and its formation has been shown to be coeval with lithospheric delamination, lithospheric mantle replacement, and widespread magmatism (Gutiérrez-Alonso et al., 2011a, 2011b).

In addition, some authors suggest the existence of another Iberian orocline, the Central Iberian bend, to the south of the Cantabrian orocline (Fig. 1A; e.g., Shaw et al., 2012). The kinematics of the Central Iberian bend are still unconstrained, and its geometry has mainly been inferred on the basis of the orientation of porphyroblasts, aeromagnetic anomalies, and paleocurrent orientations (Aerden, 2004; Martínez Catalán, 2011; Shaw et al., 2012). If so, the Cantabrian orocline and the Central Iberian bend would together define an S-shaped, continental-scale double bend (Fig. 1A), instead of single C-shaped belt defined by the Cantabrian orocline alone (Fig. 1B).

The idea that the Cantabrian orocline and Central Iberian bends formed coevally, as a coupled orocline, has two main consequences: (1) it changes the geometry of the Variscan–Alleghanian orogen, requiring a new configuration for the collisional margin of Gondwana (Shaw et al., 2014), and (2) a new kinematic model for the amalgamation of Pangea is required to explain the necessary vertical axis rotations and the large amounts of shortening. Previous studies tried to solve these problems by invoking Pangea-scale megashears or intra-orogenic subduction zones (Martínez Catalán, 2011), for which there is little evidence. In this paper, we investigate the kinematics and geometry of the puzzling Central Iberian bend and their implications for the formation of Pangea through paleomagnetic analysis.

BACKGROUND

The rocks in Iberia recorded a Cambrian rift event that culminated in opening of the Rheic ocean in the Early Ordovician, and the development of a Paleozoic passive margin sequence

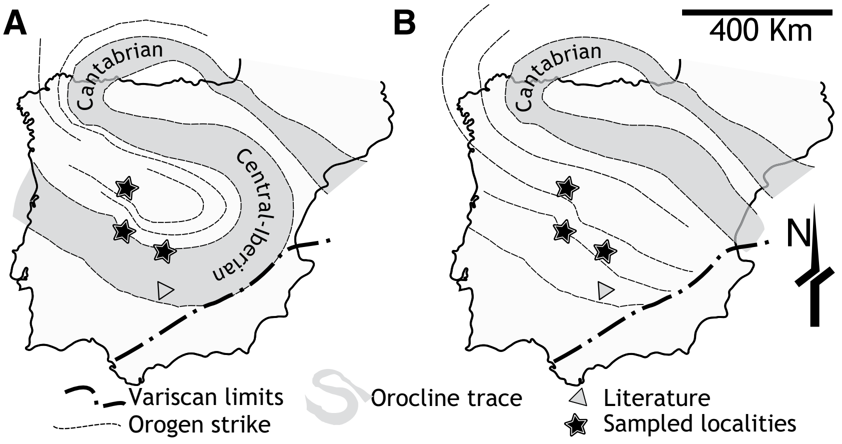

Figure 1. A: The Iberian Peninsula showing the trace of the Variscan belt, including the Cantabrian orocline and the alleged Central Iberian bend in the most extreme interpretation by Shaw et al. (2012). B: Iberian Peninsula showing the strike of the Variscan orogen with a single bend, the Cantabrian orocline. Stars are sampling localities; triangles are localities from the literature.

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that is characteristic of northern Gondwana (Murphy et al., 2006; Pastor-Galán et al., 2013; Fernández-Suárez et al., 2014). During the Early Devonian through Carboniferous, an oblique collision between Gondwana and Laurussia occurred, and rocks in the Iberian Massif were deformed, metamorphosed, and intruded by different magmatic pulses, including a ca. 310–295 Ma postfolding pulse resulting from lithospheric delamination (Quesada, 2006; Braid et al., 2011; Gutiérrez-Alonso et al., 2011a, 2011b, and references therein).

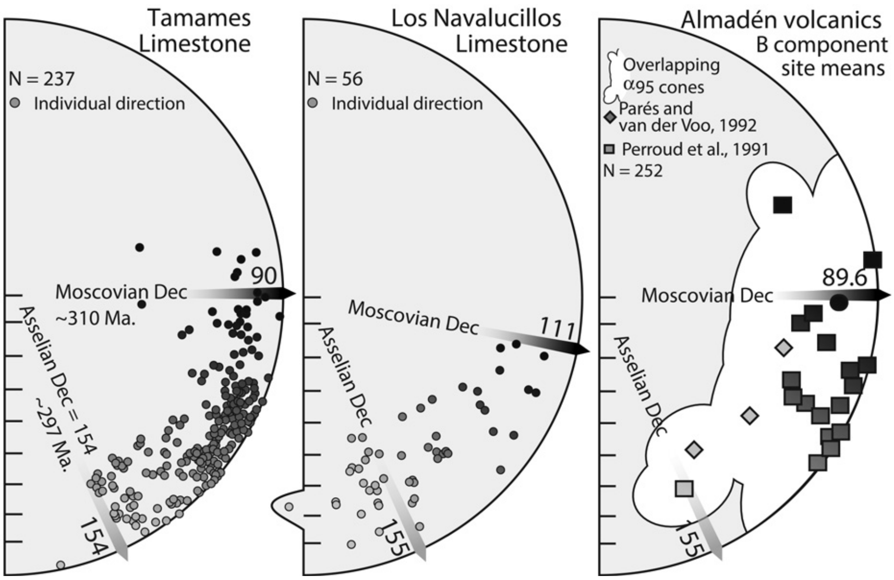

Figure 2. Equal area projection of results obtained from the Tamames Limestone, Los Navalucillos Limestone, and Almadén volcanics, showing the reference direction of each outcrop for Moscovian and Asselian time (for further information, see the Data Repository [see footnote 1]). Grayscale indicates how far or close the points are to the Moscovian and Asselian declinations (Dec).

The southern limb of the Central Iberian bend is not as well exposed as the Cantabrian orocline and Paleozoic rocks in the supposed hinge are scarce and mainly hidden beneath Mesozoic–Cenozoic basins. The rocks consist of a dominantly clastic-marine sequence that includes limestones and volcanics, which are the best paleomagnetic targets. We sampled the Tamames Limestone (Díez-Balda et al., 1995) and Los Navalucillos Limestone formations (Menéndez Carrasco, 2013), both composed of alternating limestones and dolomitic carbonates and deposited between 515 and 509 Ma. The limestones show significant lateral facies and thickness changes (from 120 to 600 m); they are affected by, at most, very low grade metamorphism. The limestones crop out in the cores of the homonymous synclines in the southern limb of the Central Iberian bend (Fig. 1; Fig. DR1 in the GSA Data Repository[1]). The volcanic rocks crop out mainly in the Almadén synform in southern Iberia (Fig. 1; Fig. DR1), and include thin lava flows, tuffs, and abundant dikes and sills. We have incorporated the previous paleomagnetic results from these volcanics into our analyses (Fig. 2; Perroud et al., 1991; Parés and Van der Voo, 1992).

PALEOMAGNETISM

We studied three localities (Fig. 1A), one in the Tamames syncline (TAM, with 237 independently oriented samples; Fig. 2; see the Data Repository) and two in different areas of the Los Navalucillos syncline (LN1, 22 samples, and LN2, 34 samples, all of them independently oriented; combined in Fig. 2). Sampling areas are located to the south of the different interpretations of axial planes for the Central Iberian bend (Aerden, 2004; Martínez-Catalán, 2011; Shaw et al., 2012). All three localities allow a fold test.

We performed standard paleomagnetism sampling, laboratory methods, and interpretation. Detailed locations of samples, methodology, and a table with the results displayed in Figure 2 are provided in the Data Repository. Characteristic remanent magnetization (ChRM) showed consistently shallow inclinations in in situ coordinates (Fig. 2). In contrast, paleomagnetic declinations in all localities showed a variety of orientations ranging from 78° to 185°, in agreement with the behavior of the B component in the Almadén volcanics (Fig. 2; Perroud et al., 1991; Parés and Van der Voo, 1992). After structural correction they become sensibly more scattered and show a negative fold test (Fig. DR3), indicating that the ChRM represents a postfolding remagnetization event.

The characteristics of the ChRM, i.e., postfolding shallow inclinations and absence of reversals, constrain its acquisition to the reversed Kiaman superchron (late Carboniferous to middle Permian). We can provide a more bracketed timing because average inclinations shallow downward, indicating that Iberia, then in equatorial latitudes, was situated in the Southern Hemisphere. Following Weil et al. (2010), Iberia crossed the equator during the early Permian, constraining the remagnetization to an interval between the Moscovian and Asselian (315–297 Ma). The widespread postfolding magmatic pulse seems the best candidate for producing a large pervasive remagnetization, constraining the remagnetization event to the interval 310–297 Ma (Gutiérrez-Alonso et al., 2011a).

SIGNIFICANCE AND TECTONIC IMPLICATIONS

Considering the postfolding character of the magnetization and its uniform inclination, the observed dispersion of ~80° in declination (Fig. 2) can only be explained in terms of vertical axis rotations. Remarkably, the dispersion is found in all three limestone localities as well as the Almadén volcanics (Fig. 2; Fig. DR1; Parés and Van der Voo, 1992). The only plausible explanation is that the observed pervasive remagnetization occurred coevally with a regional vertical axis rotation. It is known that Iberia registers no differential rotations since the early Permian (Weil et al., 2010); therefore, we calculated a reference declination for each locality (~155°; Fig. 2) based on the early Permian pole obtained by Weil et al. (2010). Using this reference direction, we found that all 4 localities rotated counterclockwise (Figs. 2 and 3) ~60° between 310 and 297 Ma.

These results are in agreement with the rotations observed in the southern limb of the Cantabrian orocline (Fig. 1C; Weil et al., 2013). However, the inferred geometry of the Central Iberian bend explicitly demands a clockwise rotation to accommodate the S shape in its southern limb, where the studied areas are located (Fig. 1A). Consequently, we calculated the idealized reference declination for each locality in a pre-Cantabrian orocline formation stage, assuming that the regional strike represents the southern limb of the convex to the west Cantabrian orocline, instead of the concave Central Iberian bend (Fig. 2; see Fig. DR4). The observed rotations confirm the correspondence of the studied localities to the southern limb of the Cantabrian orocline (Figs. 2 and 3). Kinematically, our results invalidate the formation of the Central Iberian bend during the late Carboniferous–early Permian, in contrast to what was pro-

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[1] GSA Data Repository item 2015187, methods, Figure DR1 (accurate location), Figure DR2 (Zeijderveld diagrams), Figure DR3 (fold test), and Figure DR4 (declination calculation), is available online at www.geosociety.org/pubs/ft2015.htm, or on request from editing@geosociety.org or Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301, USA.

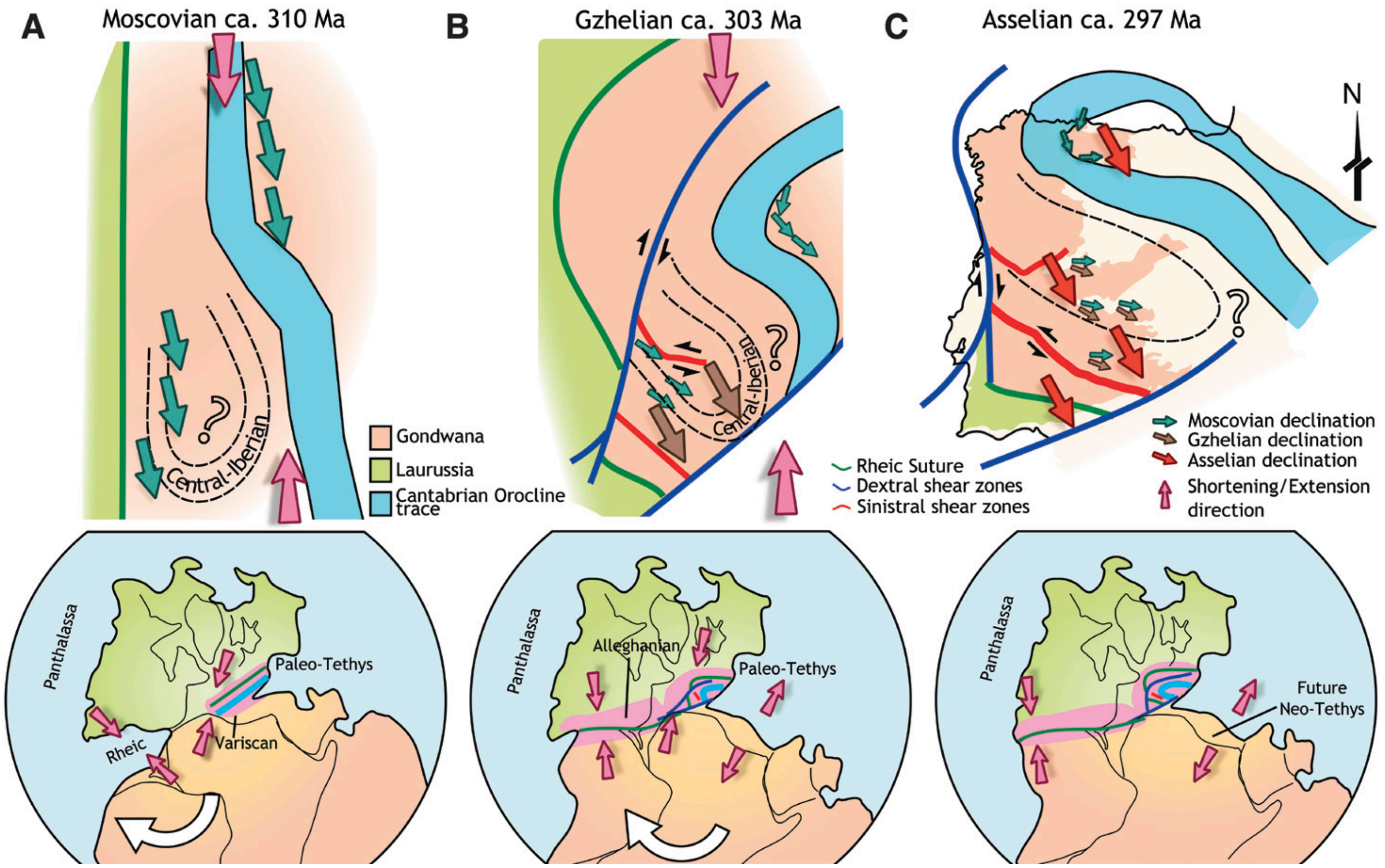

Figure 3. Latest stages of the amalgamation of Pangea and Cantabrian orocline development, highlighted by a slightly curved, roughly linear orogen (following Quesada, 2006) in which paleomagnetic directions from the Cantabrian orocline (Weil et al., 2013) and this study are shown. A change in the regional stress field, probably related to relative movement between Gondwana and Laurussia (see text) produced the buckling of the orogen, producing a C shape, and the final amalgamation of Pangea.

posed by Martínez Catalán (2011), Shaw et al. (2012), and Weil et al. (2013).

Our results only permit the Central Iberian bend, if it ever existed, to be an inherited feature formed in pre-Moscovian time. Examples of plausible mechanisms capable of producing a large-scale hairpin-bend are indentation of a sharp and large rigid block during earlier collision (e.g., Late Devonian or early Carboniferous) or precollisional rollback of a subducting slab. Until now, no evidence for either of these processes was found. We also argue that the possibility of a primary bend of such magnitude being an inherited irregularity in the continental margin (e.g., a large embayment) is unlikely.

In addition to the kinematic constraints imposed on the Variscan belt evolution, our results have important bearing on tectonic reconstructions of Pangea: they explicitly enlarge the size of the Cantabrian orocline to a plate-scale orocline that buckled around a vertical axis in ~10 m.y., referred to in the literature as the Ibero-Armorican Arc (e.g., Aerden, 2004; Weil et al., 2010). Producing such a feature requires a 90° change in the regional stress field (Fig. 3) which has yet to be included in global reconstructions of Pangea (e.g., Stampfli et al., 2013; Domeier and Torsvik, 2014).

PANGEA'S SIMPLE TWIST OF FATE

The collision between Gondwana and Laurussia occurred diachronously along a westward-younging trend (e.g., Hatcher, 2002; Weil et al., 2013; Chopin et al., 2014). The initial collision of Gondwana with Laurussia produced the Variscan belt of Europe in the Late Devonian to mid-Carboniferous. In contrast, the collision in the North American segment is not recorded until the late Carboniferous (Hatcher, 2002). The initial collision generated a roughly linear orogen in north and central Iberia (Weil et al., 2013). However, our model permits a tenuous bend concave to the west, as suggested by Quesada (1991, 2006) and Braid et al. (2011), and shown in Figure 3A (blue band). This feature was likely produced by irregularities in the Gondwanan continental margin.

We suggest that, during Moscovian time (ca. 310 Ma), Gondwana began to rotate clockwise relative to Laurussia, allowing the southern continental margins to collide after closure of the Rheic Ocean remnant, producing the Alleghanian orogen of North America (Fig. 3B; Hatcher, 2002). The rotation of Gondwana, accommodated by shortening on the western side of Pangea (Alleghanian orogen), would have produced extension in its easternmost segment (Fig. 3B). Ultimately, this extension could have been responsible for initiating the opening of the Neo-Tethys Ocean (Fig. 3C) during the Permian after the Cimmerian continent rifted apart from Gondwana (Gutiérrez-Alonso et al., 2008; Stampfli et al., 2013). This rotation phase can also explain the late Carboniferous dextral motion found throughout the Variscan–Alleghanian orogen (Hatcher, 2002; Gutiérrez-Alonso et al., 2015) and the late Carboniferous lithospheric thickening and subsequent delamination observed in the Variscides (Gutiérrez-Alonso et al., 2011a; Pastor-Galán et al., 2012), and is fully compatible with the widely accepted oblique collision between the irregular continental margins of Gondwana and Laurussia (e.g., Quesada, 2006; Braid et al., 2011)

Finally, we propose that such a rotation of Gondwana produced a buttress effect to the south of the Iberian Peninsula (Fig. 3B) that would be responsible for the change in the stress field of ~90° in the Variscan orogen, as recorded in northwest Africa and the Iberian Peninsula (Pastor-Galán et al., 2011; Chopin et al., 2014). This change in the stress field resulted in the formation of a single twist in the trend of the

Variscan orogen, the Cantabrian orocline (Fig. 3C; Weil et al., 2013).

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REFERENCES CITED

Aerden, D., 2004, Correlating deformation in Variscan NW-Iberia using porphyroblasts; implications for the Ibero-Armorican Arc: Journal of Structural Geology, v. 26, p. 177–196, doi:10.1016/S0191-8141(03)00070-1.

Braid, J.A., Murphy, J.B., Quesada, C., and Mortensen, J., 2011, 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: Geological Society of London Journal, v. 168, p. 383–392, doi:10.1144/0016-76492010-104.

Carey, S.W., 1955, The orocline concept in geotectonics: Royal Society of Tasmania Proceedings, v. 89, p. 255–288.

Chopin, F., Corsini, M., Schulmann, K., El Houicha, M., Ghienne, J.-F., and Edel, J.-B., 2014, Tectonic evolution of the Rehamna metamorphic dome (Morocco) in the context of the Alleghanian-Variscan orogeny: Tectonics, v. 33, p. 1154–1177, doi:10.1002/2014TC003539.

Díez-Balda, M.A., Martínez-Catalan, J.R., and Arribas, P.A., 1995, Syn-collisional extensional collapse parallel to the orogenic trend in a domain of steep tectonics: The Salamanca detachment zone (Central Iberian Zone, Spain): Journal of Structural Geology, v. 17, p. 163–182, doi:10.1016/0191-8141(94)E0042-W.

Domeier, M., and Torsvik, T.H., 2014, Plate tectonics in the late Paleozoic: Geoscience Frontiers, v. 5, p. 303–350, doi:10.1016/j.gsf.2014.01.002.

Domeier, M., Van der Voo, R., and Torsvik, T.H., 2012, Paleomagnetism and Pangea: The road to reconciliation: Tectonophysics, v. 514–517, p. 14–43, doi:10.1016/j.tecto.2011.10.021.

Fernández-Suárez, J., Gutiérrez-Alonso, G., Pastor-Galán, D., Hofmann, M., Murphy, J.B., and Linnemann, U., 2014, The Ediacaran–Early Cambrian detrital zircon record of NW Iberia: Possible sources and paleogeographic constraints: International Journal of Earth Sciences, v. 103, p. 1335–1357, doi:10.1007/s00531-013-0923-3.

Gutiérrez-Alonso, G., Fernández-Suárez, J., Weil, A.B., Brendan Murphy, J., Damian Nance, R., Corfú, F., and Johnston, S.T., 2008, Self-subduction of the Pangaean global plate: Nature Geoscience, v. 1, p. 549–553, doi:10.1038/ngeo250.

Gutiérrez-Alonso, G., Fernández-Suárez, J., Jeffries, T.E., Johnston, S.T., Pastor-Galán, D., Murphy, J.B., Franco, M.P., and Gonzalo, J.C., 2011a, Diachronous post-orogenic magmatism within a developing orocline in Iberia, European Variscides: Tectonics, v. 30, TC5008, doi:10.1029/2010TC002845.

Gutiérrez-Alonso, G., Murphy, J.B., Fernández-Suárez, J., Weil, A.B., Franco, M.P., and Gonzalo, J.C., 2011b, Lithospheric delamination in the core of Pangea: Sm-Nd insights from the Iberian mantle: Geology, v. 39, p. 155–158, doi:10.1130/G31468.1.

Gutiérrez-Alonso, G., Johnston, S.T., Weil, A.B., Pastor-Galán, D., and Fernández-Suárez, J., 2012, Buckling an orogen: The Cantabrian orocline: GSA Today, v. 22, no. 7, p. 4–9, doi:10.1130/GSATG141A.1.

Gutiérrez-Alonso, G., Collins, A.S., Fernández-Suárez, J., Pastor-Galán, D., González-Clavijo, E., Jourdan, F., Weil, A.B., and Johnston, S.T., 2015, Dating of lithospheric buckling: ^{40}Ar/^{39}Ar ages of syn-orocline strike-slip shear zones in northwestern Iberia: Tectonophysics, v. 643, p. 44–54, doi:10.1016/j.tecto.2014.12.009.

Hatcher, R.D., Jr., 2002, Alleghanian (Appalachian) orogeny, a product of zipper tectonics: Rotational transpressive continent-continent collision and closing of ancient oceans along irregular margins, *in* Martinez Catalán, J.R., et al., eds., Variscan-Appalachian dynamics: The building of the late Paleozoic basement: Geological Society of America Special Paper 364, p. 199–208, doi:10.1130/0-8137-2364-7.199.

Johnston, S.T., Weil, B., and Gutierrez-Alonso, G., 2013, Oroclines: Thick and thin: Geological Society of America Bulletin, v. 125, p. 643–663, doi:10.1130/B30765.1.

Martínez Catalán, J.R., 2011, Are the oroclines of the Variscan belt related to late Variscan strike-slip tectonics?: Terra Nova, v. 23, p. 241–247, doi:10.1111/j.1365-3121.2011.01005.x.

Menéndez Carrasco, S., 2013, Los Arqueociatos de la Formación Calizas de Los Navalucillos en los Montes de Toledo (España) [Ph.D. thesis]: Madrid, Universidad Complutense de Madrid, 412 p.

Murphy, J.B., Gutierrez-Alonso, G., Nance, R.D., Fernandez-Suarez, J., Keppie, J.D., Quesada, C., Strachan, R.A., and Dostal, J., 2006, Origin of the Rheic Ocean: Rifting along a Neoproterozoic suture?: Geology, v. 34, p. 325–328, doi:10.1130/G22068.1.

Nance, R.D., Gutiérrez-Alonso, G., Keppie, J.D., Linnemann, U., Murphy, J.B., Quesada, C., Strachan, R.A., and Woodcock, N.H., 2010, Evolution of the Rheic Ocean: Gondwana Research, v. 17, p. 194–222, doi:10.1016/j.gr.2009.08.001.

Parés, J.M., and Van der Voo, R., 1992, Paleozoic paleomagnetism of Almaden, Spain: A cautionary note: Journal of Geophysical Research, v. 97, no. B6, p. 9353–9356, doi:10.1029/91JB03073.

Pastor-Galán, D., Gutiérrez-Alonso, G., and Weil, A.B., 2011, Orocline timing through joint analysis: Insights from the Ibero-Armorican Arc: Tectonophysics, v. 507, p. 31–46, doi:10.1016/j.tecto.2011.05.005.

Pastor-Galán, D., Gutierrez-Alonso, G., Zulauf, G., and Zanella, F., 2012, Analogue modeling of lithospheric-scale orocline buckling: Constraints on the evolution of the Iberian-Armorican Arc: Geological Society of America Bulletin, v. 124, p. 1293–1309, doi:10.1130/B30640.1.

Pastor-Galán, D., Gutiérrez-Alonso, G., Fernández-Suárez, J., Murphy, J.B., and Nieto, F., 2013, Tectonic evolution of NW Iberia during the Paleozoic inferred from the geochemical record of detrital rocks in the Cantabrian Zone: Lithos, v. 182–183, p. 211–228, doi:10.1016/j.lithos.2013.09.007.

Pastor-Galán, D., Martín-Merino, G., and Corrochano, D., 2014, Timing and structural evolution in the limb of an orocline: The Pisuerga-Carrión Unit (southern limb of the Cantabrian Orocline, NW Spain): Tectonophysics, v. 622, p. 110–121, doi:10.1016/j.tecto.2014.03.004.

Perroud, H., Calza, F., and Khattach, D., 1991, Paleomagnetism of the Silurian volcanism at Almaden, Southern Spain: Journal of Geophysical Research, v. 96, p. 1949–1962, doi:10.1029/90JB02226.

Quesada, C., 1991, Geological constraints on the Paleozoic tectonic evolution of tectonostratigraphic terranes in the Iberian Massif: Tectonophysics, v. 185, p. 225–245, doi:10.1016/0040-1951(91)90446-Y.

Quesada, C., 2006, The Ossa-Morena Zone of the Iberian Massif: A tectonostratigraphic approach to its evolution: Zeitschrift der Deutschen Gesellschaft für Geowissenschaften, v. 157, p. 585–595, doi:10.1127/1860-1804/2006/0157-0585.

Rosenbaum, G., 2014, Geodynamics of oroclinal bending: Insights from the Mediterranean: Journal of Geodynamics, v. 82, p. 5–15, doi:10.1016/j.jog.2014.05.002.

Shaw, J., Johnston, S.T., Gutiérrez-Alonso, G., and Weil, A.B., 2012, Oroclines of the Variscan orogen of Iberia: Paleocurrent analysis and paleogeographic implications: Earth and Planetary Science Letters, v. 329–330, p. 60–70, doi:10.1016/j.epsl.2012.02.014.

Shaw, J., Gutierrez-Alonso, G., Johnston, S.T., Galan, D.P., and Pastor Galan, D., 2014, Provenance variability along the Early Ordovician north Gondwana margin: Paleogeographic and tectonic implications of U-Pb detrital zircon ages from the Armorican Quartzite of the Iberian Variscan belt: Geological Society of America Bulletin, v. 126, p. 702–719, doi:10.1130/B30935.1.

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

van der Voo, R., Stamatakos, J.A., and Pares, J.M., 1997, Kinematic constraints on thrust-belt curvature from syndeformational magnetizations in the Lagos del Valle syncline in the Cantabrian Arc, Spain: Journal of Geophysical Research, v. 102, p. 10,105–10,119, doi:10.1029/97JB00263.

Weil, A.B., Gutiérrez-Alonso, G., and Conan, J., 2010, New time constraints on lithospheric-scale oroclinal bending of the Ibero-Armorican Arc: A paleomagnetic study of earliest Permian rocks from Iberia: Geological Society of London Journal, v. 167, p. 127–143, doi:10.1144/0016-76492009-002.

Weil, A.B., Gutiérrez-Alonso, G., Johnston, S.T., and Pastor-Galán, D., 2013, Kinematic constraints on buckling a lithospheric-scale orocline along the northern margin of Gondwana: A geologic synthesis: Tectonophysics, v. 582, p. 25–49, doi:10.1016/j.tecto.2012.10.006.

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