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Paleomagnetism of the Central Iberian curve's putative hinge: Too many oroclines in the Iberian Variscides

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ABSTRACT

The Variscan mountain belt in Iberia defines a large "S" shape with the Cantabrian Orocline in the north and the Central Iberian curve, an alleged orocline belt of opposite curvature, to the south. The Cantabrian Orocline is kinematically well constrained, but the geometry and kinematics of the Central Iberian curve are still controversial. Here, we investigate the kinematics of the Central Iberian curve, which plays an important role in the amalgamation of Pangea since it may have accommodated much of the post-collisional deformation. We have performed a paleomagnetic study on Carboniferous granitoids and Cambrian limestones within the hinge of the curve. Our paleomagnetic and rock magnetic results show a primary magnetization in the granitoids and a widespread Carboniferous remagnetization of the limestones. Syn-kinematic granitoids show ca. 70° counter-clockwise rotations consistent with the southern limb of the Cantabrian Orocline. Post-kinematic granitoids and Cambrian limestones show consistent inclinations but very scattered declinations suggesting that they were magnetized coevally to and after the ~70° rotation. Our results show no differential rotations between northern, southern limb and the hinge zone. Therefore, we discard a late Carboniferous oroclinal origin for the Central Iberian curve.

1. Introduction

The latest supercontinent, Pangea, formed after several collisions during the Paleozoic that amalgamated Laurentia, Baltica, Gondwana, Siberia and an assortment of micro-continents to form a global plate (e.g. Nance et al., 2010; Domeier and Torsvik, 2014). Among the many orogens formed during the birth of Pangea, the Variscan–Alleghanian orogen in Europe and North America stands out because of its sinuous geometry. It shows several striking curves in map view: the Alabama (Thomas, 1977); Pennsylvanian (Wise, 2004); New Foundland (O'Brien, 2012); Bohemian (Tait et al., 1996; Edel et al., 2003), Cantabrian (van der Voo, 2004) and the putative Central Iberian curve (Fig. 1; e.g. Staub, 1926; Martínez-Catalán, 2011).

Orogenic curves can be classified according to their kinematics by two end members: (1) primary curves, inherited from physiographic features (e.g. gulfs, embayments) and (2) secondary oroclines, curves that form from a previously linear continental fragment. All intermediate bent orogens are termed as progressive oroclines (Weil and Sussman, 2004; Johnston et al., 2013). Oroclines are widespread in space and time (Rosenbaum, 2014), show varying curvature ranging from a few degrees to as much as 180° (Johnston, 2001), may affect the entire lithosphere (Pastor-Galan et al., 2012a) and may represent up to thousands of kilometers of shortening (Shaw et al., 2016). Most tectonic restorations consider plates as rigid bodies that move across the Earth's surface following the basic principles of plate tectonics (e.g. Stampfli et al., 2013; Domeier and Torsvik, 2014). However, oroclines are the proof that plates are far less rigid through time than reconstructions often assume. Properly identifying oroclines and unraveling their kinematics is therefore essential for accurate and viable tectonic and paleogeographic reconstructions.

The trend of the Variscan–Alleghanian belt in Iberia depicts the well-known Cantabrian Orocline in the north and an orogenic curve of opposite curvature to the south, known as the Central Iberian curve (Fig. 1; Shaw et al., 2012). After its first description in the early 20th century this curve has been largely ignored. Due to lack of exposure, some of the geometry and most of the kinematics of the Central Iberian curve are largely unknown (Pastor-Galan et al., 2015a). Nonetheless, some authors proposed that the Central Iberian curve is a secondary orocline (Martínez-Catalán, 2011, 2012; Shaw et al., 2012). This hypothesis involves hundreds of kilometers of shortening, large-scale strike-slip tectonics and/or the presence of subduction zones, which has drastic

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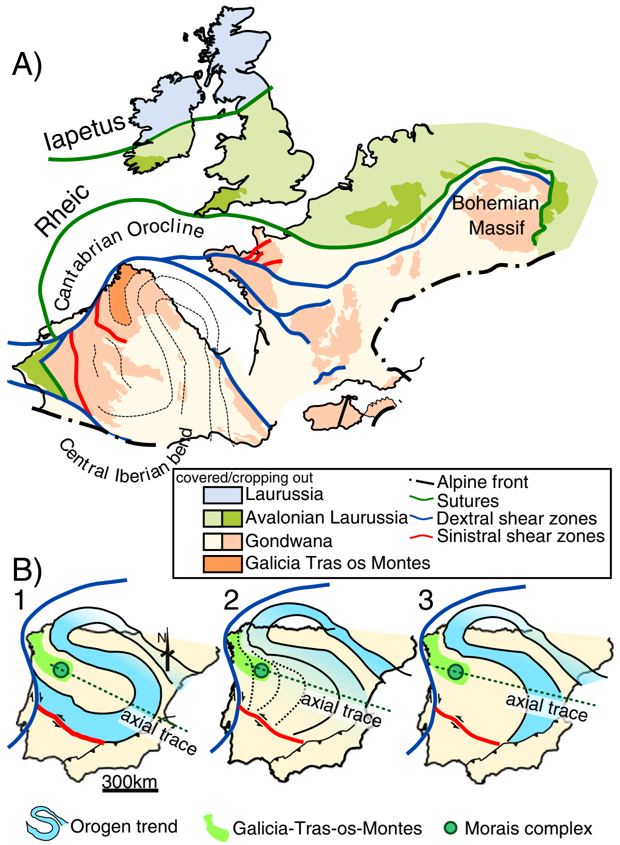

Fig. 1. A) Schematic map of the Variscan belt showing the major terranes, sutures and strike-slip shear zones and the traces of the Cantabrian Orocline and the putative Central Iberian bend. B) Different geometries suggested for the Central Iberian bend, all of them locating the Morais Complex in its core: (1) after Shaw et al., 2012; (2) after Aerden, 2004 and (3) after Martínez-Catalán, 2011.

implications for the amalgamation of Pangea including its configuration and inner stability (Martínez-Catalán, 2011; Shaw et al., 2014; Shaw and Johnston, 2016). In this paper we explore the kinematics of the Central Iberian curve in its core using paleomagnetic analysis. We sampled Carboniferous granitoids around its putative hinge and Cambrian limestones in its southern limb. Our new results indicate that formation of the Central Iberian curve is incompatible with a secondary orocline origin during the late Carboniferous. Therefore, we need an alternative kinematic model to accommodate the observed curve geometry in this part of the Variscan orogen.

2. Overview of the Variscan orogen in Iberia

The Late Paleozoic Variscan orogen of central and western Europe is generally interpreted to be the result of convergence and collision between Laurussia and Gondwana during closure of the Rheic Ocean (e.g. Scotese, 2001; Stampfli and Borel, 2002; Murphy et al., 2006; Nance et al., 2010; Nance et al., 2012; Domeier and Torsvik, 2014). It is one of the major orogenic belts that formed during the amalgamation of Pangea (e.g. Murphy et al., 2009; Stampfli et al., 2013 and references therein).

The Variscan Orogen is classically divided into a number of tectonostratigraphic zones based on fundamental differences in their stratigraphic, structural, magmatic and metamorphic evolution (e.g. Lotze, 1945; Franke, 1989; Martínez-Catalán et al., 2007; Ballevre et al., 2014). These zones record different aspects of the Late Cambrian–Early Ordovician opening of the Rheic Ocean and the migration of terranes from the margin of Gondwana towards Laurussia, as well as the tectonothermal events that accompanied the closure of that ocean. Similarities within individual zones facilitate their correlation along the length of the entire orogenic belt. Relevant to this paper are the Central Iberian Zone – not to be confused with the Central Iberian curve – and Galicia–Tras-os-Montes.

The earliest Variscan deformation in Iberia is interpreted to have occurred prior to c. 400 Ma and its origin is debated (Dallmeyer and Ibarguchi, 1990; Quesada, 1991; Gómez Barreiro et al., 2006; Martínez-Catalán et al., 2009). The first evidences of continental collision, however, occurred later, at ca. 365–370 Ma (Dallmeyer et al., 1997; Rodriguez et al., 2003; López-Carmona et al., 2014) with the underplating of the Gondwanan margin below Laurussia, giving rise to an east-northeastward (in present-day coordinates) migration of deformation, metamorphic and magmatic episodes and syn-orogenic sedimentation (Dallmeyer et al., 1997).

The magmatic history of Central Iberia can be divided into three main episodes: the first episode comprises the so called "Early Granodiorites" (Capdevila and Floor, 1970). Their ages are poorly known, but these granodiorites are interpreted to have intruded at ca. 340 Ma (Gallastegui, 2005). Subsequent "Syn-kinematic" anatectic leucogranites and granodiorites (Capdevila et al., 1973; Castro et al., 2002; López-Plaza et al., 2008; López-Moro et al., 2012) have been dated at ca. 325–318 Ma in NW Iberia (Escuder Viruete et al., 1994; Díez Balda et al., 1995; Escuder Viruete, 1998; Ferreira et al., 2000; Valverde-Vaquero et al., 2007; Costa et al., 2014; Gomes et al., 2014). These intrusive features have been related to large extensional shear zones and are interpreted to reflect the main phase of orogenic collapse (Bea et al., 2006; Castiñeiras et al., 2008). Finally, the "Post-kinematic" granodiorites, dated mostly between ca. 310 and 295 Ma, postdate all Variscan deformation and are coeval with the development of the Cantabrian Orocline. These late granitoids are interpreted to be the result of lithospheric delamination caused by orocline buckling (Gutiérrez-Alonso et al., 2011a, 2011b) or by thermal enhancement in an orogenically thickened continental crust (Bea et al., 2003; Alcock et al., 2009, 2015).

2.1. The Cantabrian Orocline

The Cantabrian Orocline (a.k.a. Ibero–Armorican Arc) is arguably one the best studied oroclines on Earth (e.g. Weil et al., 2013; Gutiérrez-Alonso et al., 2012). It is characterized by a curved structural trend that traces an arc from Brittany across the Bay of Biscay into the Central Iberian zone (Fig. 1). An assortment of geological data support a secondary oroclinal model for the Cantabrian Orocline, in which an originally near-linear Variscan orogenic edifice buckled around a vertical axis (e.g. van der Voo et al., 1997; Kollmeier et al., 2000; Weil et al., 2001; Pastor-Galán et al., 2012b). Orocline formation is constrained to a short period of ca. 10 to 15 Myr between 310 and 295 Ma based on paleomagnetic (Weil et al., 2010), structural (Merino-Tomé et al., 2009; Pastor-Galán et al., 2011; Pastor-Galán et al., 2014; Shaw et al., 2016) and geochronological data (Gutiérrez-Alonso et al., 2015). The closure of the Rheic Ocean resulted in shortening during the Devonian and Carboniferous, which produced a near-linear Variscan orogen. Subsequent change in the shortening direction close to the Carboniferous–Permian boundary resulted in oroclinal buckling (e.g. Weil et al., 2001; Pastor-Galán et al., 2011). Petrologic and isotopic data indicate penecontemporaneous magmatic and tectonothermal activity with the oroclinal buckling over the short 10–15 Myr time window at the end of the Carboniferous (Gutiérrez-Alonso et al., 2011a, 2011b). Orocline formation and large scale intrusions are thought to be part of a single process of lithospheric buckling. Buckling of the entire lithosphere would produce thinning in the outer arc, thickening in the inner arc, and ultimately foundering and delamination of the mantle lithosphere under western Europe (Fernández-Suárez et al., 2002; Gutiérrez-Alonso et al., 2004, 2011a, 2011b), an hypothesis that was successfully tested with analog modeling (Pastor-Galan et al., 2012a).