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The missing Rheic Ocean magmatic arcs: Provenance analysis of Late Paleozoic sedimentary clastic rocks of SW Iberia

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ABSTRACT

Early Carboniferous turbiditic sedimentary rocks in synorogenic basins located on both sides of the Rheic suture in SW Iberia were studied for provenance analysis. An enigmatic feature of this suture, which resulted from closure of the Rheic Ocean with the amalgamation of Pangea in the Late Carboniferous, is that there are no recognizable mid- to Late Devonian subduction-related magmatic rocks, which should have been generated during the process of subduction, on either side of it. U–Pb LA–ICP-MS geochronology of detrital zircons from Early Carboniferous turbidites in the vicinity of the Rheic suture in SW Iberia, where it separates the Ossa–Morena Zone (with Gondwana continental basement) to the north from the South Portuguese Zone (with unknown/Meguma? continental basement) to the south, reveals the abundance of mid- to Late Devonian (51–81%) and Early Carboniferous (13–25%) ages. The Cabrela and Mértola turbidites of the Ossa–Morena and South Portuguese zones, respectively, are largely devoid of older zircons, differing from the age spectra of detrital zircons in the oldest (Late Devonian) strata in the underlying South Portuguese Zone, which contain abundant Cambrian and Neoproterozoic ages. Mid- to Late Devonian zircons in the Cabrela Formation (age cluster at c. 391 Ma, Eifelian–Givetian transition) and Mértola Formation (age clusters at c. 369 Ma and at c. 387 Ma, Famennian and Givetian respectively) are attributable to a source terrane made up of magmatic rocks with a simple geological history lacking both multiple tectonic events and older continental basement. The terrane capable of sourcing sediments dispersed on both sides of the suture is interpreted to have been completely removed by erosion in SW Iberia. Given that closure of the Rheic Ocean required subduction of its oceanic lithosphere and the absence of significant arc magmatism on either side of the Rheic suture, we suggest: 1) the source of the zircons in the SW Iberia basins was a short-lived Rheic ocean magmatic arc, and 2) given the lack of older zircons in the SW Iberia basins, this short-lived arc was probably developed in an intra-oceanic environment.

1. Introduction

Deciphering the processes responsible for the closure of the Rheic Ocean is crucial to understanding the late Paleozoic amalgamation of Pangea. The Rheic suture between the two main continental blocks that made up Pangea, Laurussia and Gondwana, can be traced along the Ouachita–Appalachian–Variscan orogenic system across North America and Western-Central Europe (e.g. Matte, 2001; Nance et al., 2010) (Fig. 1).

In the northern Appalachians, terranes inferred to lie west of the Rheic suture include Avalonia and the more outboard Meguma. The Meguma terrane is exposed in southern Nova Scotia and is interpreted to extend seaward over a wide area from the Grand Banks to Cape Cod (van Staal et al., 2009). Mid–Late Devonian granitoid intrusions that have a collisional geochemical signature (Tate and Clarke, 1997; Moran et al., 2007) characterize the Meguma terrane and are interpreted to record subduction of Rheic oceanic lithosphere to the northeast beneath Laurentia (van Staal et al., 2009; and references therein). If correct, the Rheic suture is constrained to lie offshore of the North American Atlantic margin, east of the Meguma terrane (van Staal and Barr, 2012).

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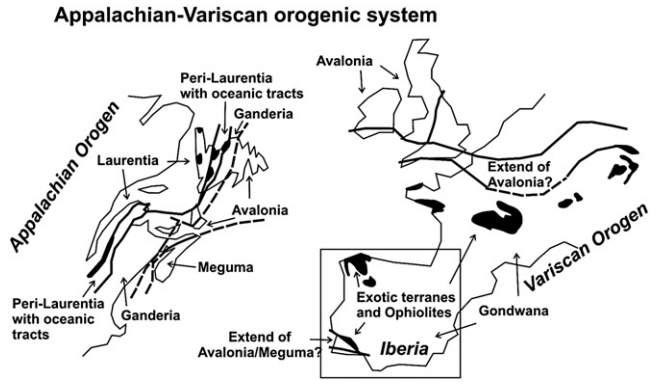

Fig. 1. The Appalachian–Variscan orogenic system prior to the opening of the Atlantic Ocean showing location of Paleozoic oceanic domains.
Modified from Martínez-Catalán et al. (2007) and van Staal et al. (2009).

The Rheic suture in SW Iberia is represented by the Beja–Acebuches Ophiolite Complex (Munhá et al., 1986; Quesada et al., 1994), which extends through western Spain and Portugal, separating the Ossa–Morena and South Portuguese zones. The Lizard suture in the British Isles is inferred to be the along-strike continuation of the Rheic suture around the Iberian–Armorican Arc, an orocline that formed by buckling of the Variscan orogenic belt in uppermost Carboniferous times (Weil et al., 2001, 2010; Gutiérrez-Alonso et al., 2008a, 2008b, 2011). There are, however, two problems with correlation of the Beja–Asebuches and Lizard ophiolitic complexes. Interpretation of the Iberian–Armorican as a single large, convex to the west bend around which units, such as the ophiolitic assemblages, were continuous, is inconsistent with recent studies showing the Variscan orogen of Iberia to be characterized by two coupled oroclines that together define an S-shaped orocline pair; a northern, convex to the west Cantabrian orocline and a southern, convex to the east Central Iberian orocline (Martínez Catalán, 2011; Shaw et al., 2012). Secondly, geochronological studies suggest that the Beja–Acebuches ophiolite, which yields crystallization ages as young as 340–332 Ma (Azor et al., 2008), may be younger than the Lizard ophiolite which is interpreted to have crystallized at 397 Ma (Clark et al., 1998). Pin and Rodrıguez (2009) have, however, documented Beja–Acebuches metagabbros that crystallized at 350 Ma and metabasalts that crystallized at 390 Ma, close to the age of the Lizard ophiolite. Regardless, the Beja–Acebuches and Lizard ophiolites both lie along and define the crustal boundary between Gondwana affinity rocks, and those of Laurentian affinity. How exactly they relate to one another remains to be determined.

The mid- to Late-Devonian closure of the Rheic Ocean, culminating in a Tournaisian continental collision (Woodcock et al., 2007; Azor et al., 2008; Braid et al., 2010), lacks a magmatic record of the subduction required to close such ocean. There are no significant mid- to Late Devonian magmatic arc rocks on either side of the Rheic suture in SW Iberia. The only record of magmatism adjacent to the suture consists of Early Carboniferous igneous rocks that are: (i) characterized by a collisional geochemical signature, (ii) found on both sides of the suture in SW Iberia, and (iii) inferred to have been emplaced after the Rheic Ocean had already closed (Santos et al., 1987; Dunning et al., 2002; Jesus et al., 2007; Pin et al., 2008; Rosa et al., 2008; Martínez Catalán et al., 2009; Murphy et al., 2009; Braid et al., 2010). The Early Carboniferous magmatism has been attributed to transcurrent slab break-off that followed oblique subduction and collision (Pin et al., 2008). The lack of a continental magmatic record of Rheic ocean closure may imply that removal of the Rheic oceanic lithosphere was accommodated almost entirely by intra-oceanic subduction (Sánchez Martínez et al., 2007). If so, it begs the question 'where is the required oceanic arc?' A possible explanation for the lack of an accreted oceanic arc adjacent to the suture is that the arc was completely removed by subsequent surface erosion. A test of this model would be to document the presence of the arc-derived sedimentary detritus preserved in basins peripheral to the suture. Detrital zircons in the syn-orogenic basins should reflect the former presence of such an arc. Sedimentary detritus can also be used to distinguish the nature of the eroded arc: oceanic arcs lack inherited crustal components and are characterized by zircons that span only the age of arc activity, whereas continental arcs are characterized by zircons attributable to arc magmatism and inheritance from the continental basement on which the arc was constructed.

In this study, LA–ICP-MS U–Pb analyses were performed on detrital zircons from four Late Devonian to Early Carboniferous syn-orogenic sedimentary clastic units preserved in basins adjacent to the Rheic suture of SW Iberia: one sample from north of the suture in the Ossa–Morena Zone, and three from south of the suture in the South Portuguese Zone (Fig. 2A) (Oliveira, 1990; Quesada et al., 1990). The syn-orogenic sedimentary rocks yielded zircon populations that include 13–91% mid- and Late Devonian ages (c. 397–359 Ma) that may have originated in the arc or arcs that developed during closure of the Rheic Ocean. We explore the possible sources for the mid–Late Devonian detrital zircon populations and use our data to constrain models of Rheic Ocean closure and Gondwana and Laurussia collision.

2. Geological setting

Iberia forms the westernmost segment of the Western and Central Europe Variscan belt that extends from Portugal to Germany (Bohemia) (Fig. 1). The Variscan orogen records the closure of the Rheic Ocean. The resulting continental collision between Laurussia to the north, and Gondwana to the south, began in the Early Devonian (Nance et al., 2010 and references therein) and ended in the Carboniferous, at c. 340 Ma, with the emplacement of ophiolites and components of the southern Laurussia margin on top of the northern margin of Gondwana (Díaz García et al., 1999; Matte, 2001; Simancas et al., 2005; Arenas et al., 2007; Martínez-Catalán et al., 2007; Nance et al., 2010).

Iberia includes five major zones with differences in their Ediacaran and early Paleozoic stratigraphy and magmatism (Fig. 2A and B): the Cantabrian, the West Asturian–Leonese, the Central-Iberian, the Ossa–Morena and the South Portuguese. The stratigraphy of the Cantabrian, West Asturian–Leonese, Central-Iberian and Ossa–Morena zones record the birth and subsequent growth of the Rheic Ocean with Cambrian rift sequences overlain by Early Ordovician to Devonian drift phase passive margin sequences (Ribeiro et al., 1990; Murphy et al., 2006; Nance et al., 2010). The Cantabrian Zone of northern Iberia comprises a succession of Paleozoic rocks that includes a Devonian sequence with a minor stratigraphic hiatus at the Frasnian–Famennian boundary (Aramburu et al., 2004). Devonian strata of the West Asturian–Leonese Zone are restricted to isolated outcrops (García-Alcalde et al., 2002). The Central-Iberian Zone lacks mid-Devonian strata (Robardet and Gutiérrez Marco, 1990).

Structurally above the northern Central-Iberian Zone there is a para-autochthonous schistose domain interpreted as meta-sedimentary strata originally deposited along the distal Gondwana passive margin. Above the schistose domain are allochthonous complexes of the Galicia–Trás-os-Montes Zone (Ribeiro et al., 1990). These include: (i) the Basal Unit, which has been interpreted as the distal margin of Gondwana subducted during the Variscan collision (Martínez-Catalán et al., 1996; Díez Fernández et al., 2011), (ii) ophiolitic units inferred to have been derived from the Rheic realm (the Purrido, Somozas, Vila de Cruces, Castriz and Careón ophiolites; Sánchez Martínez et al., 2009; 2011 and references therein), and (iii) the Upper Units of Avalonian–Laurentian affinity (Martínez-Catalán et al., 1996; Arenas et al., 2007; Murphy and Gutiérrez-Alonso, 2008) (Fig. 2C). The mafic protoliths of the Careón Ophiolite, which are interpreted to have been generated in an intra-oceanic supra-subduction zone within the Rheic Ocean (Sánchez Martínez et al., 2007, 2009), have yielded cyrstallization ages of c. 395 Ma (mid-Devonian; Díaz García et al., 1999; Pin et al., 2002), as did metagabbros of the Purrido Ophiolite (Sánchez Martínez et al., 2011).