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# The Corredoiras orthogneiss (NW Iberian Massif): Geochemistry and geochronology of the Paleozoic magmatic suite developed in a peri-Gondwanan arc

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ABSTRACT

The Corredoiras orthogneiss belongs to the intermediate pressure upper units of the Órdenes Complex (Variscan belt, NW Spain), mainly composed by granodioritic orthogneisses, with small bodies of tonalitic orthogneisses, amphibole-rich orthogneisses and metagabbronorites. In this work we study their chemical and isotopic composition, to gain insight into the linkage between plate tectonics and magmatism and to improve the knowledge of the paleogeographic evolution of the European Variscan Belt.

Granodioritic and tonalitic orthogneisses range from intermediate to felsic rocks, with $K_2O/Na_2O$ ratios $\approx 1$, typical of calc-alkaline rocks, and high $Na_2O$ content, characteristic of I-type granites. Metagabbronorites are basic rocks, but some of them are contaminated by interaction with the felsic magmas, showing enrichment in $SiO_2$, $Na_2O$ and $K_2O$. All Corredoiras metaigneous rocks are enriched in large ion lithophile elements (LILE) and light rare earth elements (LREE) relative to high field strength elements (HFSE), resulting in a high LILE/HFSE ratio. These geochemical features are the most characteristic of magmas related to subduction zones; furthermore all orthogneisses display significant negative anomalies in Ta, Nb and Zr, which together with their low contents in Y and Yb match up with granitoids generated in volcanic arcs or subduction zones.

SHRIMP U–Pb zircon dating provides a concordia age of $492 \pm 3$ Ma. Granodioritic orthogneiss has negative $\varepsilon Nd_{(492\ Ma)}$ values ($-2.2$ to $-3.6$) and high $(^{87}Sr/^{86}Sr)_i$ ratios (0.707 to 0.708), on the other hand tonalitic orthogneisses and metagabbronorites have positive $\varepsilon Nd_{(492\ Ma)}$ (1.0 to 2.4) and low $(^{87}Sr/^{86}Sr)_i$ (0.703 to 0.705), suggesting that granodioritic orthogneisses have a clear crustal influence in their generation, whereas tonalitic orthogneisses and metagabbros can be related to basic magmas extracted from the mantle or from a basic lower continental crust.

The Corredoiras chemical characteristics permit us to interpret that this rocks were probably generated in an ensialic island arc and may represent a peri-Gondwanan fragment drifted away to open the Rheic Ocean.



## 1. Introduction

The basement of the European Variscan Belt is composed of several early Paleozoic crustal fragments. The origin of these pieces has been attributed to tectonic processes that occurred along the northern margin of Gondwana during its protracted geological history involving varied events, such as plate subduction, generation of magmatic arcs and rifting (Martínez Catalán et al., 2009; Matte, 1991; Pin, 1990). The study of the chemical and isotopic composition of igneous rocks in ancient orogens like the European Variscan Belt, where the original geological relationships are extremely reworked, is very useful in the reconstruction of paleotectonic environments. Specifically, calc-alkaline affinity rocks, which are mainly generated in mature magmatic arcs, can help us to determine the existence of an ensialic basement in these arcs. This ensialic basement makes possible the appearance of geochemically evolved plutonic rocks, as it occurs in the Izu–Bonin, Cuba or New Britain arc systems, which contain volumetrically important tonalite and granodiorite batholiths (Kawate and Arima, 1998; Marchesi et al., 2007; Rojas-Agramonte et al., 2004; Woodhead et al., 1998). The study area is located in the northwestern region of the Iberian Massif, which preserves one of the best sections of the internal part of the European Variscan Belt, with several allochthonous complexes located in Galicia (Órdenes, Cabo Ortegal and the Malpica–Tui unit) and Portugal (Bragança and Morais).

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In this work, we study the chemical and isotopic composition of the Corredoiras unit, which is part of the intermediate pressure upper units (Díaz García et al., 1999b; González Cuadra, 2007). The metaigneous rocks that form part of the Corredoiras unit, include a varied range of rocks types, dominated by a granodiorite–granite association, with small amounts of tonalite and gabbro. The study of these rock associations is important to gain insight into the linkage between plate tectonics and magmatism and to improve the knowledge of the paleogeographic evolution of the European Variscan Belt.

## 2. Geological setting

The European Variscan Belt is a Devonian–Carboniferous orogen generated during the progressive collision between Gondwana and Laurussia, and the consequent closure of the Rheic Ocean (Martínez Catalán et al., 2009). The axial zone of the Variscan Belt is characterized by the presence of several allochthonous complexes constituted by exotic terranes with ophiolites and high-P metamorphic rocks (Arenas et al., 1986). These exotic terranes outline the intricate Pangea suture in Europe, which is rootless and it was transported within the allochthonous complexes towards more external regions of the Variscan Belt. In the NW Iberian Massif, five allochthonous complexes are preserved in late synformal structures: three of them outcropping in Galicia (Cabo Ortegal, Órdenes and the Malpica–Tui unit) and two in the Portuguese region of Trás-os-Montes (Bragança and Morais complexes). The Órdenes Complex is the largest one (Fig. 1) and it is constituted by basal, ophiolitic and upper units (Martínez Catalán et al., 2002, 2007).

In the Galician allochthonous complexes it is possible to distinguish several slices with different origins. These slices can be grouped in three sets of units named, from bottom to top: basal, ophiolitic and upper units (Martínez Catalán et al., 2002, 2007). These units converged at the onset of the Variscan Orogeny, and thereafter, during their accretion and exhumation, they were dismembered and thinned, reaching their present configuration as a consequence of late orogenic processes of folding and faulting (Martínez Catalán et al., 2009). As the ophiolitic units are considered to represent a collisional suture (Arenas et al., 2007a; Sánchez Martínez et al., 2007a, 2007b), the basal units are interpreted as the most external continental margin of Gondwana (Abati et al., 2010; Arenas et al., 1995, 1997; Martínez Catalán et al., 1996; Rodríguez et al., 2003), whereas the upper units represent exotic terranes with Gondwanan affinity. These upper units can be divided in two sets with contrasting pressure and temperature conditions; on one hand, the high-pressure and high-temperature units (HP–HT), occupying the lower structural position and, on the other hand, the intermediate pressure units (IP) on top of the orogenic pile (Abati et al., 1999, 2003; Fernández Suárez et al., 2007; Ordoñez Casado et al., 2001).

There is a variety of felsic metaigneous rocks in the basal and the upper units and the study of their chemical and isotopic composition is essential to establish their tectonic setting. This knowledge will contribute to the paleogeographic reconstruction of the different units recognized in the allochthonous complexes. For example, in the basal units, two igneous series with different age have been distinguished (Rodríguez Aller, 2005): an older series with calc-alkaline affinity (490–480 Ma; Abati et al., 2010; Díez Fernández et al., 2011; Santos Zalduegui et al., 1995), and a younger series with alkaline–peralkaline composition (480–470 Ma; Díez Fernández et al., 2011; Montero et al., 2009; Rodríguez et al., 2007). This bimodal magmatism and its geochemical characteristics point to a Cambro–Ordovician extensional episode in the most external margin of Gondwana that signals the origin of the Rheic Ocean (Abati et al., 2010; Díez Fernández et al., 2011; Martínez Catalán et al., 2009).

In the upper units there is a wider diversity of igneous rocks, including ultramafic, mafic and felsic types (Arenas et al., 2007b). The ages of magmatism vary between 520 and 500 Ma (Abati et al., 1999, 2007; Castiñeiras et al., 2010; Fernández Suárez et al., 2007; Ordóñez Casado, 1998; Santos et al., 2002). There are a few studies on the geochemistry of the igneous rocks in the HP–HT units (Galán and Marcos, 1997; Gil Ibarguchi et al., 1990; Mendia Aranguren, 2000) and the mafic rocks in the IP units (Andonaegui et al., 2002); however, no geochemical study has been carried out nowadays in the felsic rocks from the IP upper units.

### 2.1. Units of the Órdenes Complex

The basal units consist of metasediments alternating with granitic orthogneisses and metabasites. The sediments include phyllites, schists, metagraywakes and paragneisses. The metagranitoids have meta- to peraluminous character, and calc-alkaline, alkaline and peralkaline compositions (Abati et al., 2010; Díez Fernández et al., 2011). The metabasites have tholeiitic composition and some of them may correspond to alkali basalts. The calc-alkaline orthogneisses are related to a magmatic arc generated during subduction and they yield U–Pb ages between 490 and 475 Ma (Abati et al., 2010; Díez Fernández et al., 2011; Santos Zalduegui et al., 1995). The bimodal, partially alkaline magmatism reflects a rifting episode (Pin et al., 1992) active between 480 and 475 Ma (Díez Fernández et al., 2011; Montero et al., 2009; Rodríguez et al., 2007), which probably resulted in the breaking and drifting away of a peri-Gondwanan terrane, and the opening of the Rheic Ocean (Díez Fernández et al., 2011; Martínez Catalán et al., 2009). The basal units are interpreted as fragments of the most external edge of the Gondwanan continental margin because they are not separated from the lower allochthon by ophiolites.

The ophiolitic units crop out discontinuously underlying the upper units and they are composed of at least two different types of ophiolites (Arenas et al., 2007b). Those occupying the higher structural position represent the basal section of an ophiolite sequence, and their geochemistry indicates a supra-subduction character (Sánchez Martínez et al., 2007b). Zircon grains extracted from leucogabbros of this unit yield a concordant U–Pb age of 395 Ma (Díaz García et al., 1999a; Pin et al., 2002). The structurally lower ophiolitic units consist of greenschist facies, volcanic and plutonic mafic rocks (greenstones) and metapelites, with rare felsic orthogneisses, serpentinites, and cherts, all strongly sheared. These ophiolites are interpreted as remnants of an oceanic crust which has been related to the early opening of the Rheic Ocean, during Cambrian times (Arenas et al., 2007c).

The upper units occupy the core of the Órdenes Complex and they are composed of terrigenous metasediments, orthogneisses and metabasites (metagabbros, eclogites, mafic granulites and amphibolites), with ultramafic rocks in the HP–HT upper units. The gabbros and orthogneisses yield U–Pb ages around 500 Ma, whereas detrital zircons in the metasediments indicate a maximum depositional age of 530–500 Ma for the uppermost greenschist facies metagraywackes (Fernández Suárez et al., 2003; Fuenlabrada et al., 2010). The geochemical signature of the igneous rocks in the HP–HT upper units has been compared to MORB and related to continental rifting (Gil Ibarguchi et al., 1990), whereas mafic rocks in the intermediate P upper units have arc tholeiitic affinities (Andonaegui et al., 2002; Castiñeiras, 2005).

The Corredoiras unit is one of the intermediate pressure upper units of the Órdenes Complex (Fig. 2). It crops out to the southwest of the Complex, occupying a lower structural position (González Cuadra, 2007). This unit displays a heterogeneous deformation and distribution of metamorphism. Two burial and exhumation episodes can be deduced based on its structure, relative chronology and metamorphism, the first occurs in granulite facies conditions and the second in amphibolite facies conditions (González Cuadra, 2007). Available ages point out to an igneous protolith emplacement for this unit at 500 Ma, a first burial episode between 493 and 484 Ma, and a second episode with exhumation finished at 375 Ma (Abati et al., 1999; Dallmeyer et al., 1997). The Corredoiras Unit consists of