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Cadomian Igneous Rocks in the Retroarc Foreland Domains of the Narcea Antiform

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Abstract

The Ediacaran strata of the Narcea Antiform from the West Asturian-Leonese Zone, known as the Narcea Slates or Mora Formation, deformed prior to deposition of the unconformably overlying Terreneuvian strata. They are subdivided into the Allande and Navelgas members. The former is intruded by Ediacaran granites, granodiorites, and gabbros (ranging from 605 ± 10 to 571 ± 5 Ma), along with associated dyke swarms, and represents Mg- and K-rich magmas associated with subduction zones sourced from a subcontinental heterogeneous lithospheric mantle. The Navelgas member contains ignimbrite levels, crystalline tuffs, basalts, rhyolites, and hyaloclastic breccias (ranging from 559 ± 3 to 556 ± 3 Ma), displaying a bimodal nature indicative of extension. Both suites reveal two main episodes of magmatic activity, separated by a gap of ca. 20 m.y., which links the transition from a prolonged Ediacaran subduction to the final establishment of extensional rifting conditions.

7.1 Introduction

The Central Iberian (CIZ), West Asturian-Leonese (WALZ), and Cantabrian (CZ) Zones of the Iberian Massif comprise remains of a Cadomian retroarc basin (Fig. 7.1a). Its extensive Ediacaran basin fill is characterized by a thick succession of predominantly siliciclastic rocks (Álvaro et al., this volume), with subsidiary carbonates. Intrusive and volcanic rocks crop out only in the WALZ part of the basin (Fernández-Suárez et al. 1998, 2000; Rubio-Ordóñez et al. 2015). In addition, Díez-Fernández et al. (2010) postulated an Ediacaran back-arc sedimentary sequence lacking igneous rocks in the Basal allochthonous units of NW Iberia. Correlation with the main back-arc basin stratigraphy remains uncertain owing to their alleged allochthonous nature.

Several authors have suggested that the Ediacaran sedimentary succession was deposited in a passive margin environment, based on the scarcity of igneous rocks and the stratigraphic, petrological, isotopic, and geochemical features of the sedimentary rocks (Valladares et al. 2000, 2002, 2006; Ugidos et al. 1997, 2003, 2010, 2016, 2020). Despite these suggestions, several lines of evidence indicate that the Ediacaran rocks cropping out in central and northern Iberia may have formed in a subduction-related environment: (i) although not volumetrically major, the existing igneous rocks exhibit an unequivocal subduction-related signature; (ii) the detrital zircon signature of the Ediacaran successions shows a dominance of zircon grains with ages close to the depositional age of the rocks (Fernández-Suárez et al. 2000, 2014; Talavera et al. 2012, 2015; Naidoo et al. 2018; Pereira et al. 2015; Gutiérrez-Alonso et al. 2021; Chichorro et al. 2022), typically interpreted as indicative of orogenic or subduction-related environments, in contrast to zircon age populations of passive margins (e.g., Cawood et al. 2012); (iii) the abundance of plagioclase clasts in the Ediacaran sediments, compared to the more K-feldspar-rich Cambrian detrital rocks, suggests a primary sediment source of probable andesitic calc-alkaline

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origin associated with a subduction environment; (iv) significant differences in the nature of the Ediacaran and Cambrian sedimentary rocks, such as an ubiquitous angular unconformity (Álvaro et al. this volume, and references therein), point to a change in tectonic regime from subduction to rifting conditions (Murphy et al. 2006; Díez-Fernández et al. 2012; Pastor-Galán et al. 2013); and (v) this transition involves a dramatic change in provenance, as revealed by detrital zircon and mica grain ages (Fernández-Suárez et al. 2000, 2014; Gutiérrez-Alonso et al. 2005), geochemistry, and Sm–Nd isotopic composition of the sedimentary rocks (Nägler et al. 1995; Beetsma et al. 1995; Valladares et al. 2002; Pastor-Galán et al. 2013).

In this chapter, we review the available data on Ediacaran subduction-related igneous activity in central and northern Iberia. Given the paucity of data from the CIZ and CZ, we focus our revision on data available from the WALZ, specifically the western flank of the Narcea Antiform, where igneous rocks are more abundant and have been studied more intensively.

7.2 The Narcea Antiform Background

The Narcea Antiform (Julivert 1971; Julivert et al. 1972; Gutiérrez-Alonso 1996) is an elongated outcrop with a curved geometry (Fig. 7.1b), composed of Ediacaran rocks, mostly siliciclastic and traditionally known as the Narcea Slates or Mora Formation (de Sitter 1961). Their deposition was controlled by debris flows and turbidity currents in slope, base-of-slope, and deep-sea fans (Pérez Estaún 1978; Pérez-Estaún and Martínez 1978; Valladares et al. 2000; Ugidos et al. 2016, 2020). The Narcea Antiform lies within the core of the Late Variscan Ibero-Armorican Orocline (Weil et al. 2019).

The Ediacaran rocks of the Narcea Antiform were first deformed prior to the deposition of the lowermost Cambrian rocks that unconformably overlie them (de Sitter 1961). The main deformation in the Narcea Antiform occurred during the Late Palaeozoic Variscan orogeny, which resulted from the collision between Laurussia and Gondwana (e.g., Martínez-Catalán et al. 2021; Pastor-Galán 2022). Deformation and low-grade metamorphic gradients increase from east (CZ) to west (WALZ) (Gutiérrez-Alonso 1992, 1996; Gutiérrez-Alonso and Nieto 1996; Pastor-Galán et al. 2009). Ductile deformation by large shear zones associated with thrusts that overprint the different units in the antiform occurred at ca. 321 ± 1 Ma (Dallmeyer et al. 1997). Late Variscan deformation imparted the curved shape of the antiform, defining the Ibero-Armorican Arc in northern Iberia (Fig. 7.1a) (Weil et al. 2013, 2019; Shaw et al. 2015).

The rocks of the Narcea Antiform were intruded by a suite of ca. 450 Ma Ordovician lamprophyric dykes related to the opening of the Rheic Ocean (Murphy et al. 2006; Rubio-Ordóñez et al. 2007) and later by post-Variscan granitoids of early Permian age (Gutiérrez-Alonso et al. 2011) and Mesozoic mafic dykes. Traditionally, the Ediacaran sedimentary succession of the Narcea Antiform was considered to be a single stratigraphic unit, known as the Narcea Slates (Lotze 1956) or Mora Formation (de Sitter 1961), covering both of the domains described above. Rubio-Ordóñez et al. (2010, 2015) distinguished two units within the Narcea Antiform (Fig. 7.1b): the Allande and Navelgas members. The Allande Unit, the westernmost unit (Fig. 7.1b), is a sandy to shaly siliciclastic unit interbedded with discontinuous volcanic and volcaniclastic layers, up to 3 m thick. This member is intruded by elongated Ediacaran granite, granodiorite and gabbro plutons, along with associated dyke swarms. The Navelgas Unit, to the east and younger in age, is more shaly and contains several andesitic volcanic complexes with thicknesses up to 1 km, interbedded with siliciclastic strata. The geometric, stratigraphic, and structural relationship between both units remains unclear due to the intensity of Variscan deformation and outcropping conditions. However, Rubio-Ordóñez (2010) interpreted an unconformity between them. Their age relations have been clarified through detrital zircon populations (Fernández-Suárez et al. 2014) and the ages of the intruded and/or interbedded plutonic rocks (see below). Unconformably overlying these units, the basal conglomerates of the Cambrian Cándana/Herrería Formation contain clasts derived from the Ediacaran igneous rocks, which marks the onset of rifting conditions and the end of the Cadomian cycle in the region (Rubio-Ordóñez et al. 2004).

7.3 Igneous Rocks of the Narcea Antiform

Ediacaran igneous rocks crop out in the WALZ, especially in the western flank of the Narcea Antiform, very close to the contact with the CZ. Additionally, volcanic rocks also occur in the Villalba Antiform (or Mondoñedo-Lugo Dome, Martínez Catalán 1985), adjacent to the CIZ-WALZ contact located immediately to the west of the WALZ.

7.3.1 Plutonic Rocks

The Ediacaran plutonic rocks of the Narcea Antiform (Fig. 7.1b) were first described by Schulz (1858) as a complex granitic body. In 1882, Barrois also provided a description of these rocks, classifying them as quarzitic diorites. However, it was not until Corretgé and Carpio (1968) and Corretgé (1969) performed modern petrographic studies that these rocks were described as planar to plane-linear, medium- to coarse-grained orthogneisses with granitic to granodioritic composition. These authors were the first to recog-

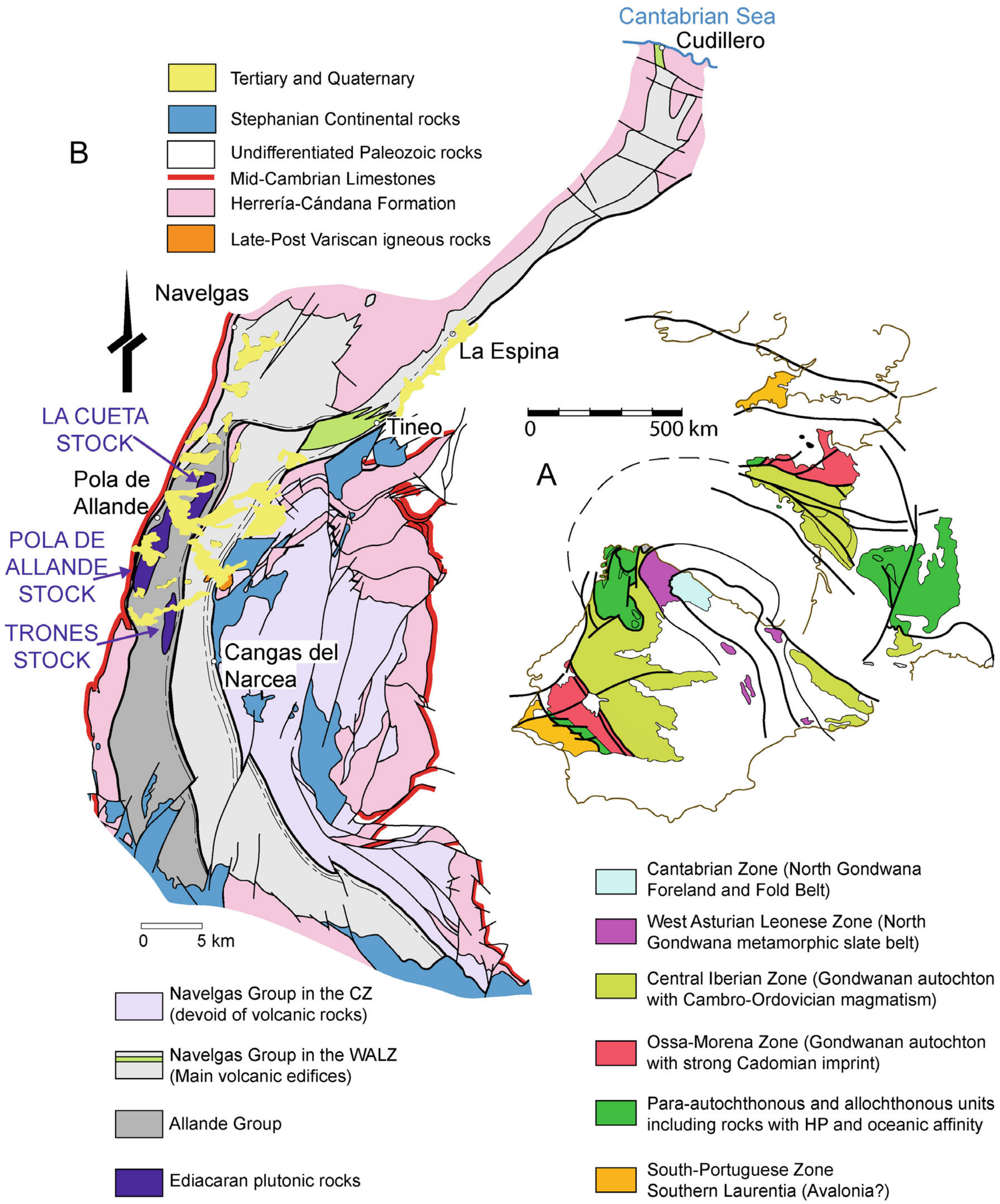

Fig. 7.1 **a** Permian reconstruction of the West European Variscan Belt, modified from Martínez Catalán (2012). **b** Geological map of the northern part of the Narcea Antiform with the tectonostratigraphic units described in the text, modified from Gutiérrez-Alonso (1996), Rubio-Ordóñez (2010) and Rubio-Ordóñez et al. (2015)

nize the intensely deformed nature of the plutonic rocks. Subsequently, Pérez-Estaún and Martínez (1978) categorized these plutonic bodies along with other foliated volcanic and volcaniclastic rocks under the term "porphyroids," describing them as "derived from the metamorphism of acidic tuffs and some levels of dacitic and rhyodacitic rocks." Gutiérrez-Alonso (1992) provided a new geological map of the area, separating the plutonic rocks from the volcanic rocks that were previously grouped together under the term "porphyroids" (see below for the main characteristics of the volcanic rocks). Gutiérrez-Alonso (1992) identified two main plutonic bodies, named the Pola de Allande and Puente de Selce

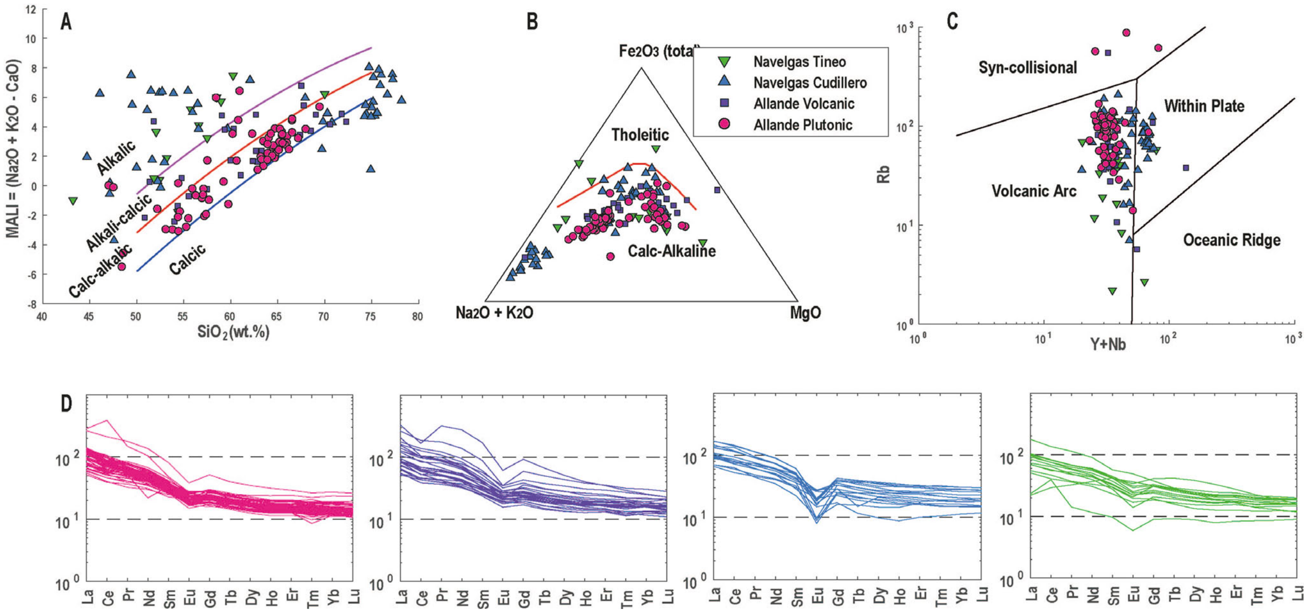

Fig. 7.2 Geochemistry of the Ediacaran plutonic rocks from the Narcea Antiform, modified from Rubio-Ordóñez (2010), Gutiérrez Alonso and Fernández Suárez (1996) and Nieto Fernández (1997). **a** SiO_2 *versus* $Na_2O + K_2O–CaO$ diagram of Frost et al. (2001). **b** AFM diagram showing whole-rock composition in terms of $Na_2O + K_2O$, total iron as FeO and MgO. **c** Y + Nb *versus* Rb plot where the incompatible elements define different tectonic settings (Pearce et al. 1984). **d** Chondrite-normalized REE diagram; chondrite values from Nakamura (1974)

stocks. All of the aforementioned studies lacked geochemical and geochronological information and attributed the rocks to Ediacaran, Ordovician, or Variscan (Carboniferous) igneous activities.

All the intrusive rocks from the Narcea Antiform are located within the Allande Unit (Fig. 7.1b). The initial geochemical data from these rocks were provided by Gutiérrez-Alonso and Fernández-Suárez (1996), who characterized them as calc-alkaline, K-rich granodiorites, and tonalites formed in a subduction environment. The Ediacaran age of these plutonic rocks was first established by Fernández-Suárez et al. (1998) using U–Pb ICP-MS-Laser Ablation, which yielded an age of 605 ± 10 Ma for the Puente de Selce stock and 580 ± 15 Ma for the Pola de Allande stock.

Rubio-Ordóñez (2010) and Rubio-Ordóñez et al. (2015) provided a more detailed map along with extensive petrographic, geochemical, isotopic, and geochronological data. They distinguished three main plutonic intrusive bodies (Pola de Allande, La Cueta and Trones, Fig. 7.1b) and several minor ones. Zircon U–Pb ages from three samples of the minor bodies range from 571 ± 5 to 575 ± 5 Ma (Rubio-Ordóñez et al. 2015), which are consistent with the previously obtained age for the Pola de Allande stock and significantly younger than the Puente de Selce (Trones) stock. The intrusive bodies consist of gabbro to granodiorite, with amphibole and biotite as the primary mafic minerals. The geochemical signature of these rocks indicates Mg- and K-rich magmas associated with subduction zones (Fig. 7.2), with SiO_2 content ranging from 47 to 70%. They were emplaced at pressures of 3–5 kb from magmas with temperatures between 850 and 1000 °C. The REE patterns (normalized to chondrite) show enrichment patterns and moderate slopes (Fig. 7.2). Sm–Nd data reveal a very homogeneous source for the intrusive rocks of the Allande Unit, with model ages consistently around 1.1 Ga, suggesting a subcontinental heterogeneous lithospheric mantle as the most likely source for these magmas.

7.3.2 Volcanic Rocks

Volcanic rocks are abundant in both the Villalba (or Mondoñedo-Lugo Dome) and Narcea antiforms. In the core of the Villalba Antiform, the "Villalba series" (Walter 1966) comprises rocks rich in plagioclase and amphibole, interpreted as volcanic rocks that were strongly metamorphosed during the Variscan orogeny. These rocks, described as "porphyroids" (Martínez Catalán 1985), are believed to represent the lower part of the Ediacaran detrital succession in this region. However, there are no updated geochemical or geochronological data available for these rocks.

The Ediacaran volcanic rocks from the Narcea Antiform occur in both the older Allande and the younger Navelgas units. However, the eastern sector of Navelgas Unit is largely devoid of these volcanic rocks (Fig. 7.1b). In the Allande Unit, there are numerous Ediacaran dykes, sills, and volcanic/volcaniclastic layers, including gabbro, diorite, diabase, basalts, andesitic pyroclastic tuffs, andesites, rhyolites, and lithic tuffs (Rubio-Ordóñez 2010). These rocks, ranging in composition from basalts to rhyolites, exhibit a subalkaline-tholeiitic affinity, suggesting that they originated in a subduction-related volcanic arc environment (Fig. 7.2). A dacitic tuff sample from the Allande Unit provided a U–Pb age of 572 ± 5 Ma, which is consistent within error with the age of the plutonic rocks encased in the same unit. This age is notably younger than that reported by Fernández-Suárez et al. (1998) for the Puente de Selce (Trones) body.

In contrast to the Allande Unit, the Navelgas Unit is characterized by two major volcanic complexes near Tineo and Cudillero (Fig. 7.1b). The Tineo complex, although strongly deformed, contains recognizable ignimbrite levels, crystalline tuffs, andesites, basalts, rhyolites and some hyaloclastic breccias, all of them affected by hydrothermal alteration (Rubio-Ordóñez 2010). The rocks from this complex are of intermediate composition and interpreted as originating from shallow submarine eruptions. The Cudillero complex was first studied by Suárez del Río and Suárez (1976) and Nieto Fernández (1997), who described the Ediacaran volcanic rocks as "porphyroids." This complex predominantly consists of pyroclastic deposits, including crystal-rich tuffs, glassy tuffs, lithic tuffs, as well as andesites and rhyolites. Unlike the Tineo complex, the Cudillero complex displays a bimodal composition (Fig. 7.1b). The ages of these complexes were established by Gutiérrez-Alonso et al. (2004), who dated rhyolites from the Tineo complex at 556 ± 3 Ma (U–Pb zircon), and by Rubio-Ordóñez (2010) and Rubio-Ordóñez et al. (2015), who reported ages of 559 ± 1 Ma for the Tineo complex and 557 ± 3 Ma for an ignimbritic rhyolite from the Cudillero complex.

7.4 Geodynamic Implications

The presence of Ediacaran igneous rocks in the Narcea Antiform reveals two episodes of magmatic activity with different geochemical features that are separated by a gap of approximately 20 m.y. The first episode, spanning from around 600–575 Ma, comprises both plutonic and volcanic rocks with a marked subduction-related volcanic arc geochemical signature, recorded in the Allande Unit, the oldest in the Narcea Antiform. The second magmatic episode is represented by the volcanic rocks from the Navelgas Unit and occurred ca. 555 Ma. Their geochemical signature is less clear (Fig. 7.1b) due to the varying degrees of alteration that has modified their original chemical composition. However, the bimodal nature of the Cudillero complex may be indicative of extension, likely heralding the onset of rifting conditions (e.g., Murphy et al. 2006).

An interesting aspect of these rocks is the insight they provide into the tectonic processes at the end of the Ediacaran in northwestern Gondwana. This interval marks the transition from the prolonged Neoproterozoic subduction of the Mirovoi Ocean beneath Gondwana to the establishment of a new tectonic cycle with rift to passive margin scenarios that lasted for most of the Palaeozoic, until the Variscan collision and the amalgamation of Pangaea.

Based on the igneous record, it is possible to interpret a first magmatic episode reflecting the final stages of subduction, with magmatic activity shifting into the back-arc basin as the subducting slab may have broken after subduction ceased, moving the magma production and shifting the magmatic arc further from the subduction trench. This episode could have been followed by the onset of extensional tectonics, which triggered the second volcanic event close to the Ediacaran–Cambrian boundary, which was heralding the beginning of rifting conditions.

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