Amazonian Mesoproterozoic basement in the core of the Ibero-Armorican Arc: $^{40}Ar/^{39}Ar$ detrital mica ages complement the zircon's tale

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ABSTRACT

The $^{40}Ar/^{39}Ar$ age data on single detrital muscovite grains complement U-Pb zircon ages in provenance studies, as micas are mostly derived from proximal sources and record low-temperature processes. Ediacaran and Cambrian sedimentary rocks from northwest Iberia contain unmetamorphosed detrital micas whose $^{40}Ar/^{39}Ar$ age spectra suggest an Amazonian–Middle American provenance. The Ediacaran sample contained only Neoproterozoic micas (590–783 Ma), whereas the Cambrian sample contained three age groups: Neoproterozoic (550–640 Ma, Avalonian–Cadomian–Pan African), Mesoproterozoic-Neoproterozoic boundary (ca. 920–1060 Ma, Grenvillian-Sunsas), and late Paleoproterozoic (ca. 1580–1780 Ma, Rio Negro). Comparison of $^{40}Ar/^{39}Ar$ muscovite ages with published detrital zircon age data from the same formations supports the hypothesis that the Neoproterozoic basins of northwest Iberia were located in a peri-Amazonian realm, where the sedimentary input was dominated by local periarc sources. Tectonic slivering and strike-slip transport along the northern Gondwanan margin affected both the basins and fragments of basement that were transferred from Amazonian to northern African realms during the latest Neoproterozoic–earliest Cambrian. Exhumation and erosion of these basement sources caused shedding of detritus to the Cambrian basins, in addition to detritus sourced in the continental mainland. The apparent dominance of Rio Negro–aged micas in the Cambrian sandstone suggests the presence of unexposed basement of that age beneath the core of the Ibero-Armorican Arc.

Keywords: Iberia, detrital mica, $^{40}Ar/^{39}Ar$ geochronology, Gondwana, Ediacaran, Cambrian.

INTRODUCTION

The origin and wander paths of the various crustal fragments that make up present-day western Europe and eastern North America have spurred geological studies for more than 100 yr. Detrital zircon U-Pb age data in sedimentary rocks provide first-order constraints on paleotectonic and paleogeographic reconstructions through their ability to fingerprint the provenance of sediments. In the Variscan belt of western Europe, they have contributed to a better understanding of the evolving paleogeography of northern Gondwana and the Iapetus Ocean (Fernández-Suárez et al., 2000, 2002a, 2002b, 2003; Gutiérrez-Alonso et al., 2003; Martínez-Catalán et al., 2004; Murphy et al., 2004a, 2004b; Collins and Buchan, 2004).

However, the high closure temperature of Pb in zircon and the lack of volumetrically significant zircon growth below upper amphibolite facies conditions means that low-temperature processes are largely invisible to zircon studies. Furthermore, as zircons are physically and chemically robust, they may be transported considerable distances from their source, either directly or through sediment recycling. The application of single-grain $^{40}Ar/^{39}Ar$ white mica thermochronology to provenance analysis complements detrital zircon studies. Muscovite is considerably less robust than zircon and its closure temperature is low (~350 °C). As a result, muscovite is unlikely to survive more than one sedimentary cycle or even long waterborne transport. The information encoded in detrital muscovite ages therefore places constraints on proximal source areas where primary muscovite-bearing rocks were present (Haines et al., 2004), and provides information on greenschist facies events and the exhumation history of the source region, which is largely invisible to U-Pb zircon studies. A limitation to the approach is that the usefulness of detrital muscovite $^{40}Ar/^{39}Ar$ ages is restricted to rocks that have not been metamorphosed above anchizone conditions.

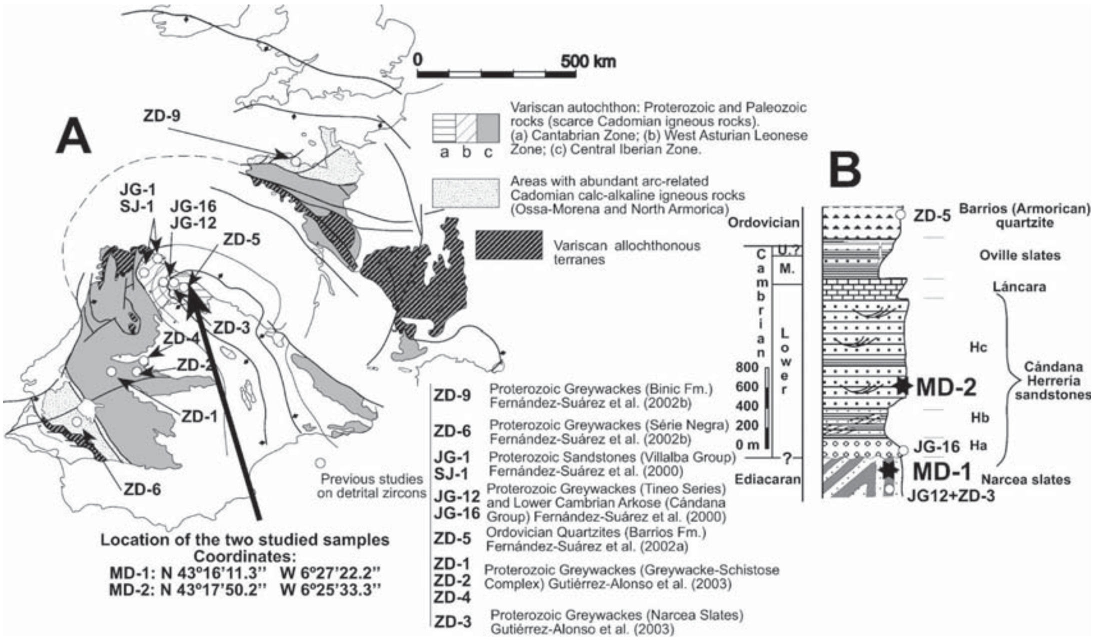
In western Europe, zircon provenance studies have proven efficient in constraining the origin and setting of Ediacaran and lower Paleozoic sediments whose basement is only locally exposed and not representative of all potential basement sources exposed at the time. Nevertheless, the interpretations are hindered by two uncertainties: the possible blurring effect of long-traveled or recycled detritus zircons, and the still-incomplete catalog of possible basement source rocks in northern Gondwana, in particular the possible presence of Mesoproterozoic rocks (ca. 0.9–1.2 Ga) in the North African realm.

The aim of this article is to show how muscovite $^{40}Ar/^{39}Ar$ age data complement detrital zircon studies and further constrain paleogeographic and tectonic models for the Ediacaran–Cambrian evolution of northwest Iberia. We present infrared-laser single-grain total fusion $^{40}Ar/^{39}Ar$ data for detrital micas extracted from samples of Ediacaran and Lower Cambrian sedimentary rocks. The $^{40}Ar/^{39}Ar$ data also contribute to understanding the nature of the basement in the core of the Ibero-Armorican Arc, where, according to paleocurrent analysis, the lower Paleozoic sediments of NW Iberia are sourced (e.g., Aramburu and García Ramos, 1993).

GEOLOGICAL AND PALEOGEOGRAPHIC SETTING

Three main paleogeographic realms can be distinguished in the West European Variscan Belt along the northern Gondwanan margin during the late Ediacaran and early Paleozoic on the basis of their geological features and detrital zircon age spectra: (1) an Ediacaran–Cambrian (Avalonian–Cadomian–Pan African) magmatic arc built on basement of varying age (Fernández-Suárez et al., 2002a, 2002b; Gutiérrez-Alonso et al., 2003; Murphy et al., 2004a, 2004b; Collins and Buchan, 2004); (2) the northern continental margin of Gondwana s.s., which consists of an amalgamation of several Archean cratons and Proterozoic basement units of different age belonging to present-day Central America, South

Figure 1. A: Simplified geological map of western Europe showing main geological units and location of samples. B: Synthetic stratigraphic column of Ediacaran and lower Paleozoic sediments in unmetamorphosed Cantabrian zone showing sample locations.



America, northern Africa, and the Arabian peninsula; and (3) a backarc basin, receiving sediments from both the arc edifice and the north Gondwana margin, where most of the Ediacaran sediments of coterminous West Europe are thought to have been deposited (Fernández-Suárez et al., 2000, 2002a, 2002b; Gutiérrez-Alonso et al., 2003). Detrital zircon ages and the Sm/Nd signatures of these rocks (Fernández-Suárez et al., 2000, 2002a, 2002b) provide evidence for the participation of Mesoproterozoic (Grenvillian s.l.) rocks in the source area for the Ediacaran sediments of northwest Iberia. This evidence has been used to postulate a peri-Amazonian location for the backarc basin in which the Ediacaran sediments were deposited.

Unconformably overlying the Ediacaran rocks is a >2000-m-thick Lower Cambrian red siliciclastic unit, deposited over most of the northern Gondwanan margin in the aftermath of the Cadomian–Avalonian–Pan African orogeny (see Fig. 1 in Avigad et al., 2003). In northwest Iberia, this unit was deposited in very shallow tidal to continental environments (Aramburu and García Ramos, 1993). Sample JG-16, collected a few meters above the Ediacaran–Cambrian unconformity (Fig. 1), contains Neoproterozoic (540–623 Ma), Mesoproterozoic (Grenvillian, ca. 1000–1100 Ma), and Paleoproterozoic–Archean (2400–2600 Ma) zircons, interpreted to be mostly recycled from the underlying sedimentary rocks (Fernández-Suárez et al., 2000). These rocks also contain abundant volcanic rock fragments very similar to those found in the Ediacaran rocks nearby.

Detrital zircon studies in Ordovician to Lower Devonian rocks of the region (Fernández-Suárez et al., 2002a; Martínez-Catalán et al., 2004) suggest that northwest Iberia was close to the west African craton in the early Paleozoic, in contrast to Ediacaran time, when northwest Iberia is interpreted to have been close to the Amazonian craton. Taken together, these hypotheses are compatible with a model of migration of the northwest Iberian Ediacaran basins along the northern Gondwanan margin and their eventual docking to a peri-African realm around the Ediacaran-Cambrian boundary or in Early Cambrian time (Fernández-Suárez et al., 2000, 2002a, 2002b; Gutiérrez-Alonso et al., 2003). However, recent studies of detrital zircons in Cambrian sedimentary rocks from the eastern sector of the northern Gondwana margin (Avigad et al., 2003) have yielded late Mesoproterozoic (Kibaran) zircons that are >3000 km away from the nearest rocks of such age, as observed in present-day exposures. This finding casts some doubt on the model of along-margin translation of northwest Iberia, which hinges on the lack of Mesoproterozoic (Grenvillian s.l.) zircons in the north African realms.

The Narcea antiform is one of the main Ediacaran exposures in northwest Iberia (Gutiérrez-Alonso, 1996) where two samples of Ediacaran and Lower Cambrian coarse-grained sandstones were collected (Fig. 1). The samples were collected in the eastern flank of the Narcea antiform (Fig. 1), where the Kübler mica crystallinity index ranges between 0.35° and 0.40° $\Delta 2\Theta$ (Gutiérrez-Alonso and Nieto, 1996), indicating that metamorphic conditions did not reach the epizone.

GEOCHRONOLOGICAL RESULTS, INSIGHTS, AND SIGNIFICANCE

The $^{40}Ar/^{39}Ar$ data are listed in the Data Repository (Table DR2[1]), and a comparison of detrital zircon and mica ages from both formations is given in Figure 2. The 12 analyzed detrital micas from the Ediacaran Narcea Slates (sample MD-1) have ages between 590 and 783 Ma. These ages date events within the Cadomian–Avalonian–Pan African arc, indicating that the Narcea Slates were deposited relatively close to the main arc edifice. These ages cluster differently from those recorded by detrital zircons in equivalent samples from the Narcea antiform (sample JG-12, Fernández-Suárez et al., 2000; sample ZD-3, Gutiérrez-Alonso et al., 2003), which range from 540 to 2517 Ma. This age mismatch suggests differences in the realms that provided sediment to the Ediacaran northern Gondwana backarc. The muscovite ages suggest that only Cadomian igneous and/or metamorphic rocks contributed mica detritus to the Ediacaran backarc basin, and that the sources contributing Grenvillian zircons were either far enough away that any micas were destroyed during transport, or did not contain primary muscovite, or contained only muscovite reset by post-Mesoproterozoic thermal events.

The Cambrian Cándana Sandstone contains micas with a more complex age spectrum. Of

[1]GSA Data Repository item 2005121, Supplemental data, Tables DR1 and DR2, and Figure DR1, geochemical data and analytical procedures, is available online at www.geosociety.org/pubs/ft2005.htm, or on request from editing@geosociety.org or Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301-9140, USA.

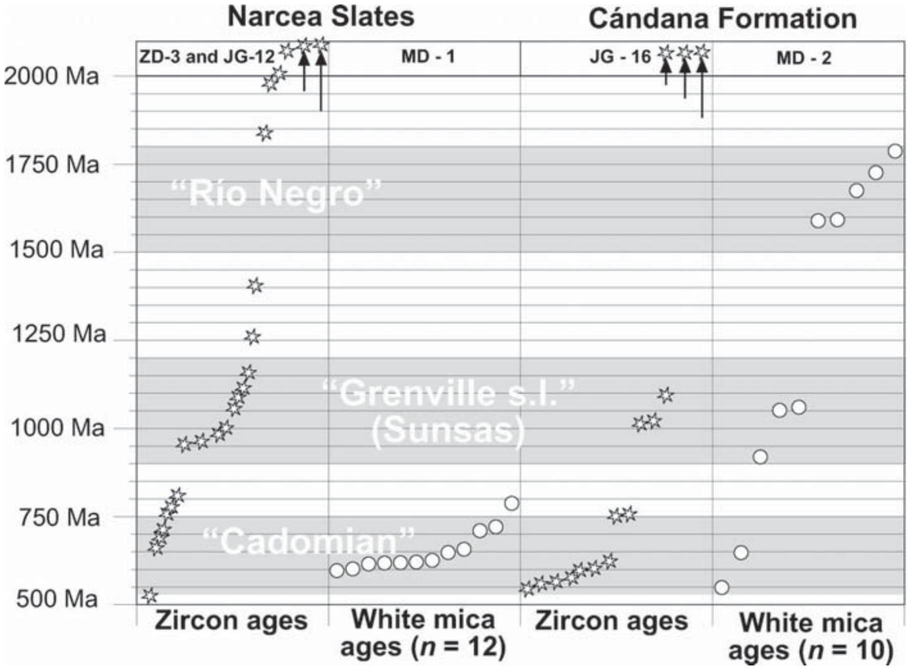


Figure 2. Comparison of detrital mica ages (this study) with detrital zircon ages from equivalent rocks (references in text). Main tectonic events to which both minerals are interpreted to be related are shown in gray.

the 12 analyzed grains, two yielded Eocene ages of 44.77 ± 2.02 and 46.70 ± 0.26 Ma. These we interpret as micas reset by fluid circulation during the Eocene uplift of the Cantabrian Mountains (Pedreira et al., 2003). The remaining 10 analyses yielded three age groups. Two grains yielded Neoproterozoic ages (644.91 ± 3.00 and 550 ± 3.39 Ma) similar to those found in the Neoproterozoic sediments, and may have been recycled from these rocks or eroded from the same basement. Three grains gave Grenvillian ages (918.38 ± 4.41, 1050.86 ± 4.82, and 1067.15 ± 4.49 Ma), and the other five micas yielded ages between 1584.6 ± 5.4 and 1784.6 ± 5.9 Ma, close to the Mesoproterozoic-Paleoproterozoic boundary.

Detrital zircons from the same formation, but from a sample (JG-16) collected closer to its base, yield Ediacaran (540–623 Ma), late Mesoproterozoic (1014–1098 Ma), and Archean (2.4–2.6 Ga) ages (Fernández-Suárez et al., 2000). The late Mesoproterozoic ages are similar to those found in the micas. However, the sample JG-16 apparently lacked zircons with ages around the Mesoproterozoic-Paleoproterozoic boundary; in northern Gondwana these are found only in the Rio Negro orogen of the Amazonian craton.

DISCUSSION

The $^{40}Ar/^{39}Ar$ data on single detrital muscovite grains complement zircon U-Pb data in provenance studies, as micas are mostly derived from proximal sources. The muscovite ages presented here, together with previously published detrital zircon data (Fernández-Suárez et al., 2000; Gutiérrez-Alonso et al., 2003), strongly suggest two different source areas for the Ediacaran Narcea Slates Formation, a proximal (periarc) source from Cadomian muscovite-bearing rocks, and a probable (but not necessarily) distal source from a late Mesoproterozoic (Grenvillian s.l.) basement, probably of Amazonian–Middle American (e.g., Oaxacan) affinity, that provided the zircons of that age (Fig. 3).

A South American origin is thus inferred from the presence of late Mesoproterozoic zircons in the age spectra of Fernández-Suárez et al. (2000). Avigad et al. (2003) found similarly aged zircons in Cambrian sedimentary rocks from northern Africa and suggested that the central African Kibaran Belt may have been their ultimate source (Fig. 3). In contrast, we suggest that the Mesoproterozoic (Grenvillian s.l.) zircons in Iberia, and similar 1100–950 Ma zircons recently reported from the Lom Basin in the northern Congo craton (Fig. 3) (Toteu et al., 2004), have an ultimate South American (Amazonian + Oaxaquian) provenance.

The proximal source for the Lower Cambrian Cándana Formation sandstone is mostly from a basement of Mesoproterozoic age in which the Rio Negro (ca. 1.5–1.8 Ga; Sadowski and Bettencourt, 1996) component appears to be dominant. The late Mesoproterozoic (Grenville s.l.) and Ediacaran zircons and muscovites may originate from a similarly aged basement source or may be recycled from the underlying Narcea Slates.

The detrital mica age spectra indicate a variety of proximal sources, and are interpreted to reflect either the migration of northwest Iberia along the northern Gondwanan margin and/or the progressive unroofing of basement rocks of different ages in the terrane on which the sediments were deposited. Subsequent erosion of this basement shed micas into the Early Cambrian basins (Fig. 3). Migration of the basement fragments would also account for the presence of Grenvillian s.l. zircons in lower Paleozoic sediments located in the northern margin of Gondwana, including the Sinai realm (Avigad et al., 2003).

Given the coastal depositional environment of the Cándana Formation (Aramburu and García Ramos, 1993; Álvaro et al., 2003), the detrital mica ages date the most recent tectonic event recorded in the rocks located close to the coast in the Early Cambrian. These rocks likely represent the unexposed basement of the Cantabrian zone, the foreland of the Variscan Belt of northwest Iberia. The evidence presented in this paper suggests that this basement consists largely of Rio Negro (1.5–1.8 Ga)-aged rocks. The turbiditic nature of the Narcea Slates Formation and the short time span recorded in the mica age spectrum suggest a periarc setting for the source. A late Mesoproterozoic basement (with rocks possibly not containing white mica) either beneath the arc or providing sediment from the other side of the basin is envisaged as the source of the Grenvillian zircons in these rocks.

The presence of late Mesoproterozoic zircons in Ediacaran–Cambrian basins in northern and central Africa (e.g., Avigad et al., 2003; Toteu et al., 2004), and the lack of tectonothermal events of equivalent age in the region, suggest that Amazonian zircons may have become widely distributed after the ca. 630 Ma amalgamation of northern Gondwana (Collins and Pisarevsky, 2005). Conversely, the preservation of muscovite grains with ages consistent with an Amazonian source suggests that the terranes forming the northwest Iberian basement have a peri-Amazonian origin, located but not exposed in the core of the Ibero-Armorican Arc.

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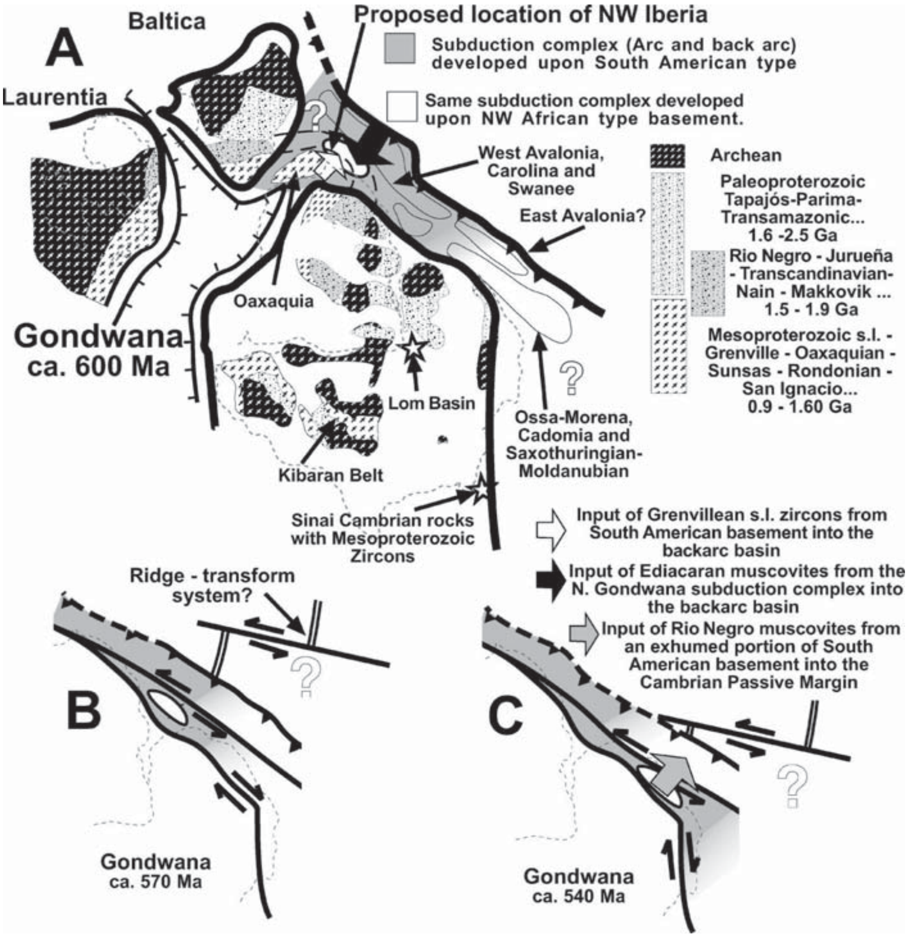

Figure 3. Ediacaran–Lower Cambrian reconstructions of North Gondwana and related terranes (modified from Gutiérrez-Alonso et al., 2003; Murphy et al., 2004b). A: Tentative location of northwest Iberian basement close to Grenvillian s.l. and Rio Negro realms correlated with inferred sources of detrital zircons and muscovites. Other realms and basins mentioned in text are starred. B, C: Proposed transfer of basement sources along northern margin of Gondwana. These basement units are thought to have shed zircons and muscovites into Cambrian basins in periphery of northern Africa.

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