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Iberian late-Variscan granitoids: Some considerations on crustal sources and the significance of "mantle extraction ages"

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ABSTRACT

A suite of post-tectonic granitoids (mostly peraluminous, broadly I-type granodiorites and monzogranites) and mafic rocks from NW Iberia with crystallization ages between ca. 309 and 290 Ma has been investigated for Sm–Nd isotopes and inherited zircon content in order to constrain the nature of their source rocks. ε_{Nd} values (at 300 Ma) vary from −0.2 to −5.9 and T_{DM} values range from 1.01 to 1.58 Ga. Inherited (xenocrystic) zircons yielded ages ranging from 458 to 676 Ma, with 90% of data between 490 and 646 Ma, corresponding to Neoproterozoic (mostly Ediacaran), Cambrian and Ordovician ages. Only three highly discordant analyses yielded ages older than 650 Ma. Based on the data reported herein and relevant data from the literature we contend that post-tectonic granitoids of the Iberian Variscan Belt (with exception of the scarce anatectic S-type granitoids) were derived mostly from metaigneous lower crustal sources which in turn were ultimately derived from a subcontinental lithospheric mantle enriched between ca. 0.9 and 1.1 Ga. I-type granitoids and mantle-derived mafic rocks both underwent varying degrees of contamination by a metasedimentary lower crust depleted in pre-650 Ma zircon (through previous melting episodes) with a time-integrated Sm–Nd evolution different to that of the metaigneous lower crust. Participation of this metasedimentary crust in the genesis of these granitoids may account for Nd isotopic variability and Nd model ages well in excess of 1.2 Ga.

1. Introduction

The genesis of granitoids and their attendant scenarios, sources and evolution processes are still a matter of intense debate among igneous petrologists. Moreover, granitoid magma can originate by melting of source rocks ranging from the upper crust to the mantle. The generation of granitoid magma takes place at the sites where first order geodynamic processes occur and therefore understanding the petrogenesis of granitoid rocks provides insights into the processes of crustal growth and recycling during Earth's evolution.

In general, we know more about granitoids generated at subduction environments (continental and island arcs) and the causes of their geochemical and isotopic variability are reasonably well constrained. Granitoids generated in collisional orogenesis are more difficult to understand. Calc-alkaline "I-type" granitoids generated in collisional environments pose an important problem. Although they share some of the geochemical characteristics of calc-alkaline granitoids generated in subduction environments, their geodynamic scenario is more complex as is the nature of their crustal sources. In fact, as many granite petrologists would agree, the "granite problem" is really a "source problem" (e.g. Castro, 2004).

The Iberian Variscan Belt (IVB) is an extraordinary example of granite genesis in a post-collisional environment. The so called late-Variscan granitoid suite of Iberia represents a voluminous post-tectonic magmatic event that took place after the main episodes of Variscan collisional deformation. The granitoid plutons belonging to this suite are post-tectonic with respect to the structures/fabrics generated by convergence and subsequent extensional collapse of the orogenic belt. (e.g. Fernandez-Suarez et al., 2000a and references therein). With the exception of volumetrically minor S-type granitoids generated by crustal anatexis at relatively low pressures, the late-Variscan granitoid suite of Iberia is essentially formed by calc-alkaline granodiorites and monzogranites with subordinate amounts of mafic rocks (Villaseca et al., 2009). These granitoids are voluminous compared to the size of the Variscan orogenic belt. They occur across the entire section of the belt including the foreland basin (Cantabrian Zone) although they are

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volumetrically more abundant towards the hinterland at the current level of erosion and exposure (Fernandez-Suarez et al., 2000a and references therein).

In this paper we present geochemical, Sm–Nd isotopic analyses and inherited zircon U–Pb ages of a set of samples belonging to the late-Variscan granitoid suite of NW Iberia and we use these data in conjunction with pertinent data from the literature to further investigate the issue of the genesis of post-collisional (late-Variscan) granitoids, their sources and the significance of their Sm–Nd isotopic signature.

Our approach aims at providing an understanding of granitoid magma genesis in the wider context of the crustal growth (and recycling) history of a lithospheric unit and the geodynamic scenarios whereby such growth takes place.

2. Geological setting

Although heterogeneously deformed by the Late Palaeozoic Variscan Orogeny, Northwestern Iberia exposes one of the most complete sections of the Paleozoic passive margin of northern Gondwana (Fig. 1). In this region, Palaeozoic rocks lie within the tightly curved core of the Iberian–Armorican Arc (Fig. 1). If this arc is restored to a pre-Variscan geometry (Weil et al., 2001; Weil et al., 2010), the Iberian continental platform of Gondwana is shown to be extremely extensive and locates northwest Iberia adjacent to West Africa along the southern flank of the Rheic Ocean throughout the Palaeozoic (Robardet, 2002; Robardet, 2003; Martínez Catalán et al., 2007; Nance et al., 2010).

The Palaeozoic rocks of the Iberian Massif are traditionally divided into zones based on differences in their Lower Palaeozoic sedimentary successions, which are interpreted to reflect their relative proximity to the Gondwanan margin (Fig. 1). From the ancient coastline seaward towards the Gondwanan outer platform, five such zones are identified of which three of them have been studied in this work. The Cantabrian Zone (CZ) preserves a coastal environment and constitutes the foreland fold and thrust belt of the IVB, whereas the West Asturian Leonese (WALZ), Central Iberian (CIZ) and Galicia Tras-os-Montes (Schistose Domain) Zones, together with the Ossa-Morena Zone of southern Iberia, preserve a more outboard tectonostratigraphy (Julivert et al., 1972; Quesada, 1990; Ribeiro et al., 1990; Perez Estaun et al., 1991; Quesada, 1991; Martinez Catalan et al., 1997; Gutiérrez-Marco, 1999; Marcos and Farias, 1999; Martínez Catalán et al., 1999; Aramburu, 2002; Robardet, 2002; Robardet, 2003; Robardet and Gutiérrez-Marco, 2004) and contain the geological record of the orogenic hinterland. Boundaries between these zones are major Variscan thrusts and reverse faults that were, in some cases, reactivated by extension in the aftermath of the Variscan Orogeny (Martinez Catalan et al., 1997; Martinez Catalan et al., 2003).

Closure of the Rheic Ocean is recorded in northwest Iberia by the deformation associated with the Laurussia–Gondwana collision, the

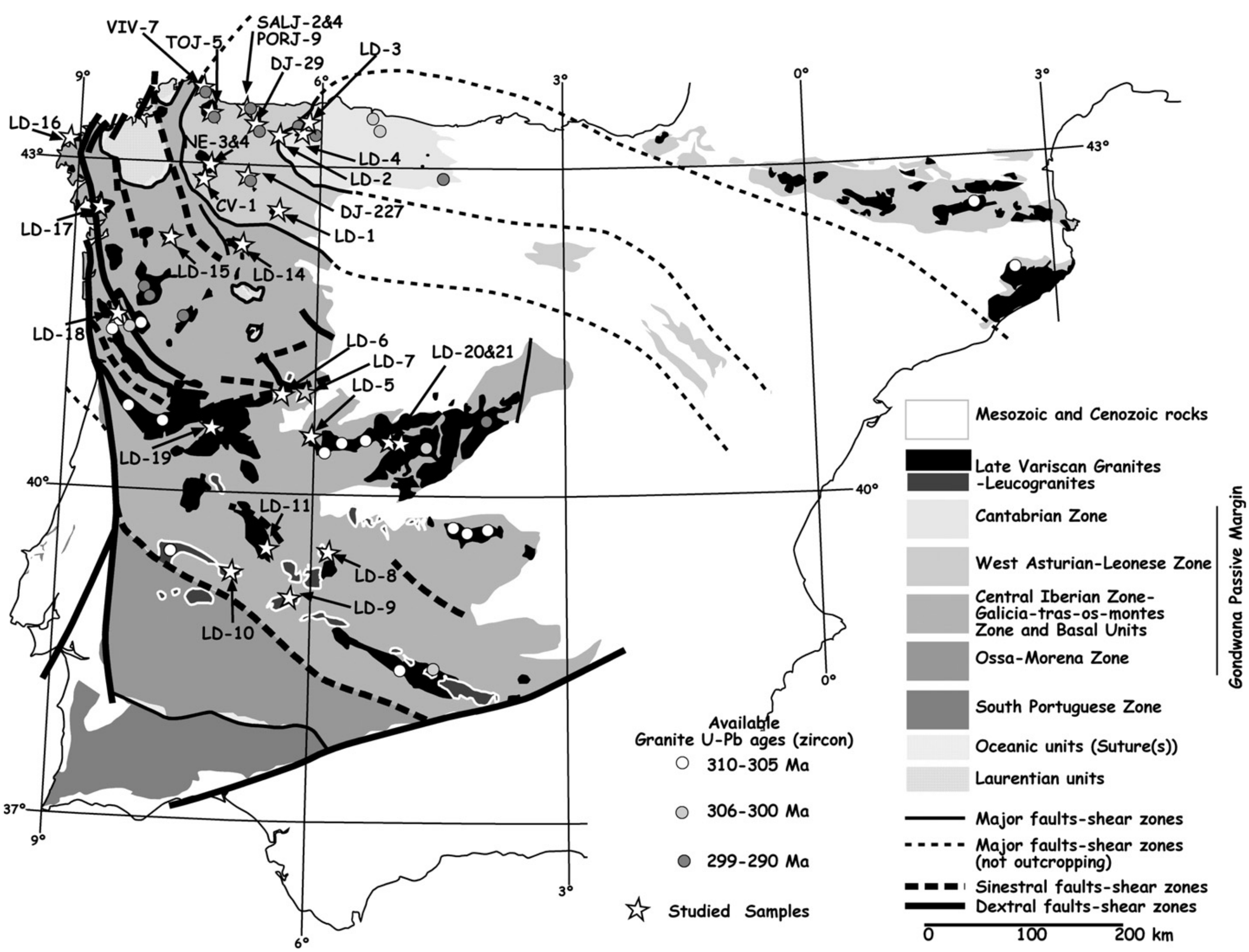

Fig. 1. Geologic sketch depicting the different Variscan paleogeographic units, major tectonic accidents in Iberia and late-Variscan (<310 Ma) granitoids. The studied samples are shown as stars, and other geochronological data of late-Variscan granitoids from the literature are expressed as grey coded circles.

Variscan Orogeny, and in the oceanic remnants preserved as ophiolites in the suture between these continents (Fig. 1). The earliest evidence of oceanic closure is recorded by northward subduction of the Rheic Ocean along the Laurussian margin, the onset of which occurred before ca. 400 Ma (Dallmeyer and Ibarguchi, 1990; Mendia and Ibarguchi, 1991; Barreiro, 2006; Fernandez-Suarez et al., 2006; Martinez Catalan et al., 2009). Subduction of the Rheic mid-ocean ridge by 395 Ma (Woodcock et al., 2007; Gutierrez-Alonso et al., 2008a) is thought to have caused an increase in the convergence rate and the coupling of both oceanic margins (Gutierrez-Alonso et al., 2008a).

The onset of continental collision began at ca. 365 Ma (Dallmeyer et al., 1997) with initial subduction of the Gondwana margin (Basal Units) below Laurussia. Deformation of the Gondwanan passive margin succession caused by the subsequent overriding of Gondwana by Laurussia migrated eastward in space and time. Convergence initially produced recumbent folds (D1) that verge and migrate from the suture towards the present-day core of the Iberian–Armorican Arc. Continued shortening is thought to have led to the extensional collapse (D2) of the thickened orogenic hinterland (Viruete et al., 1994; Arenas and Catalan, 2003; Pereira et al., 2009) at ca. 320 Ma (Martinez Catalan et al., 2009). This event was coeval with the development of a non-metamorphic foreland fold-thrust belt within the Cantabrian Zone (Perez Estaun et al., 1994). Final deformation associated with the closure of the Rheic Ocean (D3) produced large-wavelength upright folds and strike-slip ductile shear zones (Martinez Catalan et al., 2009). Immediately following ocean closure, and coevally with the intrusion of the igneous rocks studied herein, an abrupt change in the stress–strain field associated with Pangaea amalgamation caused a dramatic 180° rotation of the IVB to produce the Iberian-Armorican Arc. The development of the Iberian–Armorican arc was accompanied by a major thermal event that has been interpreted to record Late Carboniferous–Early Permian lithospheric delamination (Fernandez-Suarez et al., 2000a; Weil et al., 2001; Gutiérrez-Alonso et al., 2004; Gutierrez-Alonso et al., 2008a; Weil et al., 2010).

3. Summary of geological and petrological features of the granitoids and geochronological constraints

Granitoids are the main igneous feature of the IVB and they occupy about 15% of total exposure, with a larger percentage in the hinterland (CIZ) and diminishing quantities towards the foreland (WALZ and the CZ) (Fig. 1). One of the most striking features of the late-Variscan granitoid magmatism is its occurrence in the foreland fold-thrust belt of the orogenic belt, which is a rare feature in collisional orogens (e.g. Fernandez-Suarez et al., 2000a). This paper is focused on the post-collisional (late-Variscan) granitoids whose main exposures in the Cantabrian, Westasturian–Leonese and Central Iberian Zones are shown in Fig. 1. As stated above, the term late-Variscan applies to granitoids whose emplacement postdates the main episodes of crustal shortening related to the Variscan Orogeny and also the subsequent extensional collapse of the orogenic belt. The crystallization ages of these granitoids (based on U–Pb zircon and monazite dates) range from ca. 309 to 290 Ma (Dias et al., 1998; Fernandez-Suarez et al., 2000) and post-date by ca. 20–30 My the peak of migmatisation and crustal melting associated with the extensional collapse of the orogenic belt (Viruete, 1998; Bea et al., 2006; Castineiras et al., 2008).

The late-Variscan granitoid suite is predominantly composed of granodiorite–monzogranite intrusions, minor tonalite and mafic-intermediate rocks, and leucogranitoid intrusions. The main petrological and geochemical features are described below and are illustrated in Figs. 2 to 5. The granodiorite–monzogranite plutons (e.g. Caldas de Reis and Neira in Table 1) are the dominant rock type and are made up of biotite ± amphibole granodiorite and biotite monzogranite. Amphibole-biotite tonalite and quartz-diorite occur as

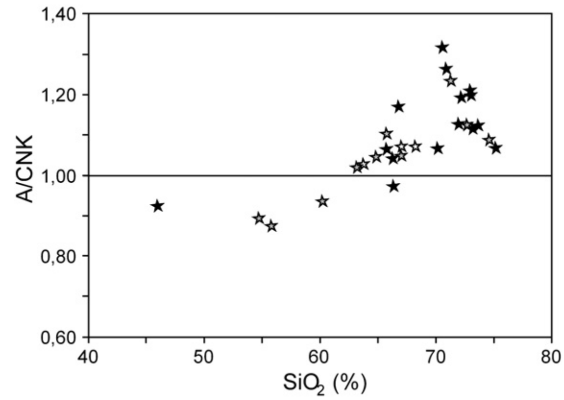

Fig. 2. SiO_2 vs. A/CNK (molar) diagram of the studied samples. White stars are samples from the Cantabrian zone; grey ones from the West-Asturian Leonese zone; and black ones from the Central Iberian zone.

microgranular enclaves in most plutons. Leucogranitic rocks (e.g. Ancares and Traba in Table 1) include two-mica (usually Ms>Bt) or muscovite leucomonzogranites, alkali feldspar granites and aplites occurring as dykes or forming the apical parts of plutons. Micro-granular igneous enclaves are lacking and metasedimentary xenoliths are common.

Mafic rocks (mostly diorites, gabbros and quartz-diorites) are scarce in the late-Variscan igneous suite and occur either as discrete small intrusions (e.g. Porcia and El Alamo in Table 1) or spatially associated to the granodiorite–monzogranite plutons. Although this study focuses on granitoids, Tables 1 and 2 report chemical and isotopic analyses of representative samples from three of these mafic intrusions (samples SALJ-2, PORJ-9 and LD-20) for reference. The petrogenesis of these mafic intrusions has been the object of several detailed studies (Suarez et al., 1990; Morenoventas et al., 1995; Galan et al., 1996; Bea et al., 2006; Orejana et al., 2009) and will not be further described here.

4. Samples and analytical methods

Twenty nine samples representing 27 late-Variscan plutons were used for this study. Major, trace and rare earth element analyses were performed on all 29 samples and Sm–Nd isotopes were analysed for 18 samples. In addition, zircons were separated from 20 samples in order to perform a preliminary study of the inherited/xenocrystic zircon component in these granitoids.

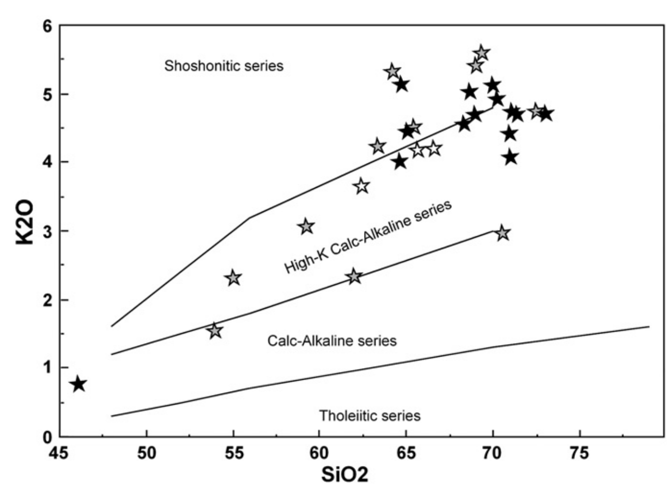

Fig. 3. K_2O vs. SiO_2 (Pecerillo and Taylor, 1976). Stars are grey coded as in Fig. 2.

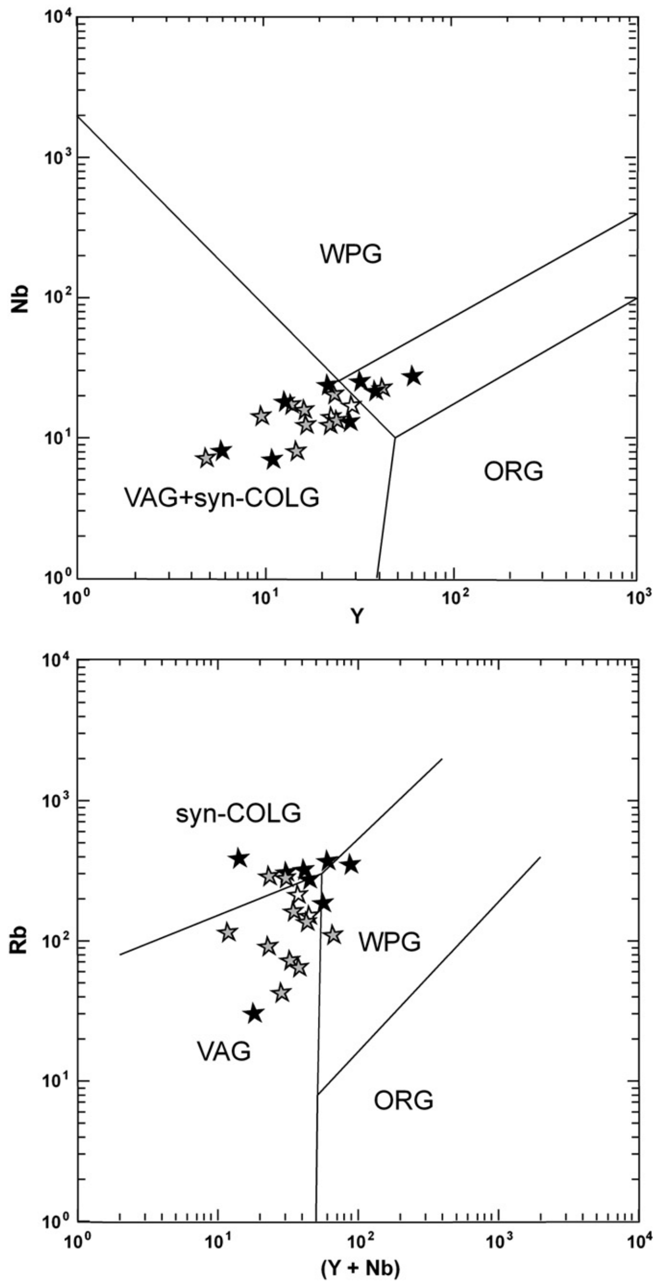

Fig. 4. Y vs. Nb and Y + Nb vs. Rb diagrams (Pearce et al., 1984). Stars are grey coded as in Fig. 2.

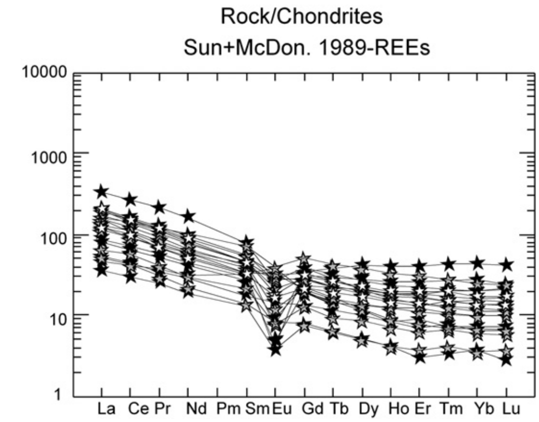

Fig 5. Normalised REE plot for selected samples of granitoids. Normalisation values of (Sun and McDonough, 1989). Stars are grey coded as in Fig. 2.

The analytical methodology and procedures for major, trace, rare element analyses, Sm–Nd isotopes and U–Pb dating of xenocrystic zircon are described in Appendix DR1. The results are shown in Tables 1, 2 and 3 of the DR1 document.

5. Major and trace element geochemistry

Of the 29 samples used in this study, one sample is a microgranular mafic enclave in the Neira pluton (sample NE-3), three correspond to minor mafic intrusions (samples SALJ-2, PORJ-9 and LD-20) and the remaining samples are granitoid rocks (biotite ± amphibole granodiorites, biotite monzogranites and biotite + muscovite leucomonzogranites) (Table 1). As regards their spatial distribution (Fig. 1), 3 samples are from the Cantabrian Zone, 11 from the Westasturian–Leonese Zone and 15 are from the Central Iberian Zone.

Leucogranitoids (Table 1, see also Fernández-Suárez, 1994; Fernandez-Suarez et al., 2000a) are classified as leucomonzogranites and leucogranodiorites. They are peraluminous (A/CNK >1, Fig. 2) granites with low Ca and Mg contents (CaO<1.3%, MgO<0.7%). Following the nomenclature of Debon and Lefort (1988), these granitoids define a leucocratic s.s. (<7% dark minerals) high aluminous (A ≈ 30–90), sodi-potassic (K/(Na + K) ≈ 0.3–0.6) association with vertical trends in the A–B diagram (Fernandez-Suarez et al., 2000a).

The granodiorite–monzogranite intrusions are peraluminous to slightly metaluminous granitoids that define “alumino-cafemic” associations of calc-alkaline type (Debon and Lefort, 1988). The rocks define calc-alkaline trends in modal composition in the QPF diagram of Debon and Le Fort (Fernández-Suárez, 1994; Fernandez-Suarez et al., 2000a). Many of these rocks display some of the characteristic features of infracrustal I-type granitoids: high Na, A/CNK typically <1.1 (except in differentiated facies), K_2O/Na_2O mostly comprised between 1 and 1.5 for granodiorites and monzogranites, presence of amphibole and absence of primary muscovite, associated molybdenum-gold mineralization in some cases. The K_2O vs. SiO_2 plot (Fig. 3) shows the high-K nature of the granitoids. On the basis of their main geochemical features they could be classified as high-K calc-alkaline to shoshonitic granitoids. However, the post-collisional tectonic setting of these granitoids implies that they cannot be readily compared with calc-alkaline granitoids from subduction environments or with the classic I-types as originally described in the Lachlan Fold belt of Australia (e.g. Chappell and White, 1992). In the IVB most late-Variscan granodiorite-monzogranite plutons fit the *mP-lP* (medium-low peraluminous) types of Villaseca et al. (1998) whereas the leucogranitoids fit the *fP* (felsic peraluminous) type of the above authors.

In tectonic discrimination diagrams (Pearce et al., 1984) shown in Fig. 4, the late-Variscan granitoids plot mostly within the syn-collisional + volcanic arc granite fields.

These granitoids show in general moderate REE contents and moderately fractionated REE patterns (Fig. 5) with $(La/Yb)_N$ between ca. 4 and 18 and Eu anomalies with Eu/Eu* values ranging from ca. 0.8 to 0.4 (Villaseca et al., 2009).

6. Nd isotope results

The Sm–Nd isotopic composition of the 18 samples analysed is given in Table 2 (DR1) and shown in Fig. 6 in an age vs. ε_{Nd} diagram. The initial isotopic ratio (expressed in epsilon units, ε_{Nd}) was calculated for an age of 300 Ma as all dated intrusions have crystallization ages ranging from ca. 309 to 290 Ma (see above).

The $^{147}Sm/^{144}Nd$ values range between 0.0979 and 0.1480. The ε_{Nd} (at 300 Ma) varies between −0.2 (microgranular enclave in the Neira pluton, sample NE-3) and −5.9 (Braga pluton, sample LD-18). Nd model ages (T_{DM}) (DePaolo, 1981; DePaolo, 1988) range between 1.01 and 1.58 Ga (Table 2 and Fig. 6). These results are comparable with those reported in other studies of granitoids belonging to the late-Variscan igneous suite (e.g. Villaseca et al., 2009). It should be noted that (based on the current data set) there is no apparent correlation of ε_{Nd} and T_{DM} values with significant geochemical parameters, element concentrations or elemental ratios (e.g. the Porcia metaluminous quartz-diorite, sample PORJ-9 and the Ancares peraluminous leucogranite, sample DJ-277 have very similar $\varepsilon_{Nd(i)}$ and T_{DM} values). Furthermore, T_{DM} values in granitoids are very similar to those reported in coeval mafic rocks in the IVB (Morenoventas et al., 1995; Bea et al., 2006; Orejana et al., 2009). In the studied granitoids (Table 2) the T_{DM} values overlap those of the mafic rocks analysed by the above authors (T_{DM} ca. 0.94 to 1.35 Ga). Moreover, a similar range in T_{DM} values is found in pre-Variscan (Ediacaran to Ordovician) mafic rocks and granitoids (Fernandez-Suarez et al., 1998; Murphy et al., 2008; Sanchez-Garcia et al., 2010).

7. Inherited zircon ages

In addition to recording crystallization ages, zircons analyzed from the late-Variscan granitoids may preserve evidence of the age of their source rocks as well as the assimilation of country rocks during magma ascent and emplacement.

It should be stated that owing to the small size of the zircons analysed in the selected samples and the technique utilized (LA-ICP-MS) the U–Pb data reported in Table 3 correspond to zircons whose size was large enough to accommodate an analysis. Therefore these results should be taken with some caution although we are confident that the number of grains analysed (Table 3) and the fact that only 3 zircons with pre- Late Neoproterozoic (discordant) ages were found (Table 3) grant the discussion that follows. Of the 20 samples investigated for this study, xenocrystic zircon was found only in 11 granitoids. Table 3 shows the results of the U–Pb analyses carried out in such xenocrysts. The table contains 57 concordant analyses out of an initial set of 81 analyses of which 21 (younger than 650 Ma) were rejected because of high discordance. As discordance in LA-ICP-MS analyses can be caused by any combination of i) lead loss, ii) analyses of mixed aged domains, iii) high common Pb; we consider that those analyses should not be used in further discussions as corrections or assumptions do not warrant that the interpreted age is correct. In this table we also show the isotopic ratios and ages of three analyses corresponding to the only three zircons that yielded discordant ages older than 650 Ma.

The 57 concordant zircon analyses, whose isotopic ratios and derived ages are given in Table 3 and shown in a Wetherill Concordia plot in Fig. 7, have ages ranging from 458 to 676 Ma, with 90% of data comprised between 490 and 646 Ma, corresponding to Neoproterozoic (mostly Ediacaran), Cambrian and Ordovician ages. Only three highly discordant analyses (Table 3) yielded ages older than 650 Ma. The data suggest that most of the inherited zircons in late-Variscan granitoids of the IVB have been ultimately originated in zircon-forming events between 650 and 490 Ma, i.e. mostly within the time span of the Cadomian orogeny and the initial rifting that led to the opening of the Rheic Ocean in the northern margin of Gondwana (Murphy et al., 2006; Linnemann et al., 2008; Nance et al., 2008; Nance et al., 2010).

8. Discussion

Taken together, our data allow an assessment of the relationship between the Sm–Nd isotopic signature and the age and possible nature of crustal sources in post-collisional granitoid rock.

8.1. Neodymium isotopes

The granitoid with the highest T_{DM} value (Villavieja de Yeltes, sample LD-6) also has the highest apparent amount of xenocrystic zircon (Table 3) suggesting that higher zircon inheritance represents a higher degree of crustal assimilation and/or restite entrainment. In this regard it is noteworthy that in a detailed study of spinel-bearing inclusions of metasedimentary origin in late-Variscan granitoids and mafic rocks from the Cantabrian Zone, Suarez et al. (1992) found ample evidence for crustal assimilation at temperatures in excess of 800 °C in many of these intrusions. Samples PORJ-9 (Porcia Pluton), SALJ-2, 4 (Salave Pluton) with high T_{DM} values (1.37–1.52 Ga) represent two of the intrusions reported by Suarez et al. (1992) to contain a high amount of spinel-bearing inclusions. Unfortunately no data on xenocrystic zircon content are available for these plutons. Samples from the Linares and Arcellana plutons (LD-2 and LD-4) have lower T_{DM} values (1.28 and 1.24 Ga respectively) than the Porcia and Salave samples (Suarez et al., 1992) and also contain lesser amounts of restitic (metasedimentary) inclusions. In this study, only one zircon (574 ± 15 Ma) xenocryst was analysed in the Linares pluton (Table 3). A study by (Klotzli et al., 2001) reports inherited lower crustal mineral assemblages (granulitized mangerites) in Variscan granites from the South Bohemian Batholith. Zircons separated from these inclusions yielded dominant Cadomian ages (590–500 Ma) with an age peak similar to that found in this study (Fig. 7).

Zircons from the Ancares and Tojiza plutons (samples DJ-277 and TOJ-5 with high T_{DM} values of 1.48 and 1.51 Ga respectively) were not analysed in this study but Fernandez-Suarez et al. (2000a) found a significant amount of inherited zircon component in a U–Pb ID-TIMS study of zircons from those same samples.

Conversely, both mafic rocks and granitoids that appear to have a lesser degree of crustal contamination have lower T_{DM} values defining a relatively narrow range between ca. 0.95 and 1.2 Ga. This is also shown in a recent study by (Orejana et al., 2009) in which geochemically primitive gabbroic rocks of the Spanish Central System (Central Iberian Zone) have T_{DM} values in the range 0.9–1.1 Ga. This range is also typical of pre-Variscan igneous rocks as shown by the data of Sanchez-Garcia et al. (2008) for Cambrian (ca. 520 Ma) mafic rocks, Montero et al. (2009) for Ordovician (ca. 480 Ma) peralkaline granites, Murphy et al. (2008) for Ordovician volcanics (ca.460 Ma) and by Fernandez-Suarez et al. (1998) for Ediacaran (ca. 600 Ma) I-type calc-alkaline granitoids in northern Spain, and Castro et al. (2003) for early Variscan (ca. 345 Ma) mafic rocks.

Within our data set, those granitoids that show limited evidence for crustal contamination and in which no inherited zircons were detected in this study (e.g. Neira, Caldas de Reis, Merida plutons) have $T_{DM} < 1.2$ and are within the T_{DM} range (0.9–1.1 Ga) of the putatively primitive and uncontaminated mantle derived mafic rocks reported by Orejana et al. (2009). The geochemistry of these granitoids also matches the main geochemical features of infracrustal (I-, *lP*-type) granitoids of Villaseca et al. (1998, 2009).

There is a remarkable match between the range of T_{DM} values in late-Variscan granitoids and the range of T_{DM} values in lower crustal metaigneous xenoliths of the Spanish Central System (1.05 to 1.53 Ga) reported in (Villaseca et al., 1999). The T_{DM} range in these metaigneous xenoliths (extending to values higher than 1.2 Ga) could reflect processes of crustal contamination during the magmatic history of the protoliths in the same manner as observed in the late-Variscan granitoids and mafic rocks.

The above analysis indicates that not even the most primitive and uncontaminated mafic rocks have Nd isotopic compositions that match that of the depleted mantle at the time of formation (see Table 2, and also Murphy et al., 2008; Orejana et al., 2009). Therefore we argue that the lineage of most crustal igneous components in Iberia can be traced to a sub-continental lithospheric mantle enriched between ca. 0.9 and 1.1 Ga (Murphy et al., 2008).

Table 1
Major, trace and REE composition of selected granitoids.

Sample	Pluton	Rock type	SiO2	TiO2	Al2O3	FeO(t)	MnO	MgO	CaO	Na2O	K2O	P2O5	A/CNK (molar)	Rb	Sr	Ba	Y	Zr
SALJ-2	Salave	Qtz-diorite	55.81	1.29	16.14	8.45	0.14	6.57	6.61	2.37	2.31	0.31	0.88	61.4	433.9	658.0	25.60	172.30
SALJ-4	Salave	Amph-Bt Granodiorite	63.24	1.05	16.81	6.72	0.11	1.53	4.39	3.61	2.33	0.21	1.02	70.5	686.4	1337.0	17.40	248.30
PORJ-9	Porcia	Qtz-diorite	54.61	1.26	18.25	7.32	0.11	6.00	8.08	2.50	1.55	0.31	0.89	42.7	546.6	581.0	17.00	156.60
DJ-29	Boal	Bt-Ms Monzogranite	72.57	0.27	15.41	1.66	0.04	0.76	1.66	4.55	2.96	0.12	1.12	112.8	234.9	255.0	5.73	98.94
DJ-277	Ancares	Bt-Ms Leucogranite	74.63	0.15	14.08	1.21	0.06	0.33	1.00	3.64	4.77	0.14	1.10	282.5	76.5	256.3	10.48	52.83
TOJ-5	Tojiza	Amph-Bt Granodiorite	65.73	0.50	17.75	3.47	0.05	1.08	3.25	2.69	5.32	0.17	1.10	90.8	223.5	2636.0	15.80	301.80
CV-1	C. Verde	Amph-Bt Granodiorite	67.05	0.58	15.90	4.01	0.08	1.74	3.03	2.91	4.52	0.18	1.05	160.2	204.6	609.0	23.60	170.00
NE-3 (E)	Neira	Microgranular enclave	60.25	1.03	17.41	6.52	0.11	2.45	4.86	3.89	3.07	0.41	0.94	108.3	258.2	730.0	44.80	408.00
NE-4	Neira	Amph-Bt Granodiorite	64.87	0.80	16.35	4.97	0.08	1.98	3.05	3.35	4.25	0.28	1.04	132.7	188.5	771.0	24.40	312.30
VIV-7	S.Ciprian	Bt-Ms Monzogranite	70.94	0.25	16.69	1.43	0.03	0.72	1.12	3.25	5.39	0.17	1.26	277.2	89.3	417.0	14.90	141.60
LD-1	Ponferrada	Bt-Ms Monzogranite	71.25	0.29	15.32	1.50	0.06	0.49	0.93	2.86	5.57	0.18	1.23	284.5	102.2			
LD-2	Linares	Bt Granodiorite	68.29	0.52	15.35	2.79	0.06	1.17	2.36	3.33	4.22	0.17	1.07	213.0	217.6	602.7	23.57	202.73
LD-3	Arcellana	Amph-Bt Granodiorite	63.81	0.71	16.6	3.86	0.09	2.19	3.84	3.19	3.66	0.18	1.03	130.9	312.6			
LD-4	Carlés	Amph-Bt Granodiorite	67.18	0.54	15.79	2.86	0.06	1.52	2.84	3.11	4.19	0.14	1.07	145.5	267.0	785.5	29.57	186.11
LD-5	La Alberca	Amph-Bt Granodiorite	66.74	0.62	15.77	3.34	0.07	1.45	1.74	3.32	4.47	0.32	1.17	226.0	164.3			
LD-6	Villavieja de Yeltes	Bt-Ms Monzogranite	72.99	0.28	14.51	1.42	0.05	0.46	0.76	3.56	4.41	0.32	1.21	306.7	40.6	195.3	13.35	104.57
LD-7	Cipérez	Bt-Ms Monzogranite	70.88	0.36	14.9	1.95	0.06	0.57	0.8	3.18	4.72	0.33	1.26	318.9	51.4			
LD-8	Trujillo	Bt-Ms Monzogranite	73.01	0.23	14.83	1.09	0.03	0.34	0.6	4.17	4.06	0.54	1.20	383.5	33.6	118.2	6.25	64.55
LD-9	Mérida	Bt-Ms Monzogranite	73.52	0.27	13.85	1.68	0.05	0.35	0.76	3.58	4.7	0.13	1.12	360.3	40.9	194.3	39.18	167.11
LD-10	Alburquerque	Bt-Ms Monzogranite	72.01	0.27	14.72	1.49	0.04	0.42	0.81	3.69	5.12	0.37	1.12	309.9	38.2			
LD-11	Cabeza de Araya	Bt-Ms Monzogranite	72.17	0.35	14.27	1.85	0.04	0.63	0.67	3.29	4.92	0.31	1.19	187.8	44.9			
LD-14	Veiga	Bt-Ms Monzogranite	70.16	0.42	14.82	2.31	0.06	0.87	1.94	3.3	4.56	0.22	1.07	184.7	149.0			
LD-15	Orense	Bt-Ms Monzogranite	73.17	0.25	14.24	1.37	0.06	0.39	0.74	3.82	4.74	0.1	1.12	316.5	44.0	279.0	29.14	123.05
LD-16	Traba	Bt-Ms Leucogranite	75.19	0.17	13.27	1.03	0.04	0.26	0.54	3.88	4.7	0.03	1.07	349.4	22.0	118.7	63.62	112.54
LD-17	Caldas de Reis	Amph-Bt Granodiorite	66.31	0.53	16.04	3.35	0.08	0.63	2.4	3.99	5.13	0.2	0.97	180.7	144.2	929.6	33.53	432.12
LD-18	Braga	Amph-Bt Granodiorite	65.74	0.91	15.77	3.64	0.07	1.33	2.18	3.09	5.32	0.47	1.06	268.7	251.4	1125.4	22.81	325.71
LD-19	Guarda	Bt-Ms Monzogranite	70.55	0.45	14.88	2.60	0.07	0.75	0.68	2.8	5.03	0.29	1.32	320.6	63.0			
LD-20	El Álamo	Gabbro	46.11	0.73	12.63	11.38	0.18	17.24	5.46	1.77	0.78	0.18	0.92	30.5	245.8	228.4	11.84	116.93
LD-21	El Mirón	Amph-Bt Granodiorite	66.22	0.66	15.89	3.53	0.05	1.44	2.71	3.63	4.01	0.34	1.04	174.7	163.2			

Major elements in wt.% oxide and trace elements in parts per million. Reported volatile free. See text for discussion of techniques and associated errors.

Granitoids and mafic rocks with T_{DM} values significantly in excess of ca. 1 Ga may reflect varying degrees of contamination with metasedimentary crustal components. An alternative scenario that produced high T_{DM} values by different degrees of mixing of Variscan depleted mantle melts with varying proportions of Neoproterozoic, Paleoproterozoic or Archaean (metasedimentary + metaigneous) crust is unlikely as it would probably have produced a much wider range of T_{DM} values. Moreover, as the same range of T_{DM} values occurs in early Palaeozoic and Neoproterozoic granitoids and mafic rocks, the most likely explanation is that the T_{DM} values reflect extraction from a mantle enriched around 1 Ga. An alternative scenario in which mixtures of contemporaneous depleted mantle and crust occurred in the same proportions so as to yield the same narrow range of T_{DM} values in mafic rocks and I-type granitoids in tectonothermal events ranging from ca. 600 to 300 Ma is considered highly unlikely.

Our view is therefore that mafic rocks in the IVB derive from a ca. 0.9 to 1.1 Ga isotopically enriched and geochemically heterogeneous sub-continental lithospheric mantle (SCLM) (Murphy et al., 2008) and the granitoids (including the late-Variscan suite) are derived from crustal (igneous) protoliths whose ultimate source is the same SCLM, as reflected in their narrow range of T_{DM} values (ca. 0.95–1.2 Ga). Higher T_{DM} values are attributed to significant crustal assimilation of metasedimentary protoliths with a different time-integrated Sm/Nd. An argument in favour of the above can be found in the work of Bea et al. (2007) and Montero et al. (2007) who studied the Ordovician (ca. 495–480 Ma) volcanic and plutonic rocks of the Ollo de Sapo domain in Central Spain (CIZ). These authors found that the Ollo de

Nb	Hf	Ta	Pb	Th	U	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
13.20	2.37	0.82	11.72	7.00	1.40	26.30	54.20	6.58	26.30	5.65	1.60	5.34	0.80	4.99	1.01	2.89	0.42	2.59	0.40
16.60	3.30	1.17	34.00	13.18	1.96	44.8	84.90	9.85	36.0	6.83	1.53	5.53	0.79	4.47	0.84	2.27	0.31	2.02	0.28
12.30	1.48	0.83	7.41	6.47	1.14	27.80	54.2	6.33	24.1	4.75	1.86	3.97	0.57	3.34	0.66	1.77	0.25	1.60	0.24
7.58	1.66	1.46	17.08	6.39	2.38	11.7	25.1	2.75	9.87	2.02	0.45	1.55	0.23	1.24	0.22	0.59	0.10	0.57	0.09
14.10	1.20	3.11	17.61	8.35	2.65	14.4	33.8	3.70	13.3	3.16	0.43	2.51	0.33	2.07	0.38	0.99	0.16	0.98	0.14
8.60	0.95	0.50	23.00	7.33	0.94	34.2	62.0	6.94	26.5	4.80	2.14	3.95	0.51	3.18	0.67	1.97	0.26	1.63	0.24
12.50	2.29	1.36	22.94	17.06	4.78	39.0	80.3	9.22	34.20	6.66	1.19	5.52	0.83	4.83	0.93	2.66	0.36	2.46	0.36
23.00	2.54	1.58	15.95	9.11	2.92	35.5	82.4	10.8	45.5	10.5	2.17	10.1	1.52	9.14	1.77	4.90	0.67	4.01	0.58
20.10	2.89	1.30	18.00	13.20	3.01	43.2	90.7	10.7	39.8	7.75	1.74	6.55	0.94	5.22	0.98	2.70	0.36	2.21	0.32
17.00	4.08	2.18	32.63	22.60	10.09	34.8	73.3	8.35	29.4	5.99	0.67	4.34	0.58	2.85	0.48	1.22	0.17	1.10	0.16
			31.20	14.80															
14.03	4.76	0.83	18.90	16.70	0.72	29.01	61.70	6.45	24.16	4.88	0.99	4.55	15.01	4.34	0.83	2.22	0.39	2.35	0.34
			25.10	19.60															
17.70	4.89	0.90	21.60	23.10	0.94	48.57	93.50	10.72	39.66	7.03	1.04	6.21	21.40	5.70	1.12	3.24	0.51	2.93	0.43
			25.50	18.50															
18.58	2.72	1.81	25.60	18.50	0.57	19.13	40.74	5.07	19.46	4.15	0.28	3.98	11.47	3.02	0.48	1.18	0.20	1.14	0.17
			28.20	23.20															
8.11	1.69	1.48	22.30	10.10	0.26	8.59	18.72	2.44	8.88	2.02	0.22	1.58	5.10	1.28	0.24	0.51	0.09	0.64	0.07
21.57	3.64	1.88	34.00	27.40	1.14	31.42	68.27	8.06	29.61	6.81	0.44	6.47	21.05	7.19	1.47	4.31	0.69	4.77	0.63
			23.20	15.90															
			28.50	12.00															
			34.10	15.40															
13.80	3.16	1.71	35.10	22.80	0.85	20.77	44.68	5.55	21.64	4.74	0.54	4.91	14.44	5.34	1.07	3.07	0.53	3.53	0.56
27.93	4.72	2.66	51.90	31.70	1.44	11.14	25.70	3.61	14.87	4.97	0.23	7.13	21.65	10.74	2.31	6.74	1.10	7.54	1.07
25.18	8.36	1.13	31.70	21.40	1.23	49.34	101.98	12.06	45.23	8.71	1.57	7.94	14.72	7.06	1.31	3.75	0.54	3.46	0.54
24.65	7.22	0.95	35.70	42.10	1.08	81.54	169.04	20.51	77.39	12.08	1.58	8.17	41.18	5.30	0.92	2.33	0.33	1.94	0.29
			24.00	21.60															
7.01	2.22	0.20	1.60	2.80	0.41	13.00	27.45	3.41	13.76	2.72	0.84	2.81	2.64	2.55	0.49	1.48	0.19	1.24	0.18
			31.00	24.00															

Sapo igneous rocks contain an unusually high proportion of inherited zircon (e.g. most samples contain a zircon population in which over 60–70% of imaged grains contain inherited cores). The T_{DM} values for representative samples reported by these authors are mostly higher than 1.6 Ga. In sum, we consider that the apparent narrow range of T_{DM} values found in mafic rocks and granitoids that have experienced limited crustal (metasedimentary) assimilation is geologically significant and points to the primordial origin of the Iberian lower crust in (or after) latest Mesoproterozoic–earliest Neoproterozoic times.

8.2. Zircon inheritance

Although some pre-Ediacaran zircons were found in our study, signaling the presence of pre- late-Neoproterozoic populations, most inherited zircons dated in the late-Variscan granitoids are not older than ca. 650 Ma (Table 3) and they can be considered to have been formed mostly during events related to the Cadomian arc-building orogeny in northern Gondwana (Nance et al., 2008; Nance et al., 2010).

A geochronological U–Pb study of zircons from lower crustal granulite xenoliths from the Spanish Central System (Central Iberian Zone) (Fernandez-Suarez et al., 2006) also failed to detect any zircon older than ca. 600 Ma and found a range of inherited zircon ages similar to those of inherited zircon in the granitoids studied herein. In addition, the "granulitic" zircons in these xenoliths yielded ages between ca. 308 and 285 Ma, an age range remarkably similar to that of late-Variscan granitoids.

Studies of zircon inheritance in pre-Variscan (Ordovician) igneous rocks have shown the existence of a subordinate but significant

Table 2
Sm–Nd isotope data.

Pluton	Sample	Nd (ppm)	Sm (ppm)	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd$	2σ	Epsilon (0)	Epsilon (300)	T_{DM}
Cantabrian Zone									(Ma)
Linares	LD 2	23.22	4.88	0.13	0.51	5	−6.3	−3.6	1284
Arcellana	LD 4	40.66	7.64	0.11	0.51	8	−7.9	−4.6	1236
West Asturian Leonese Zone									
Salave	SALJ-2	26.3	5.65	0.13	0.51	6	−6.7	−4.1	1373
Salave	SALJ-4	36	6.83	0.13	0.51	5	−8.1	−5.5	1495
Porcia	PORJ-9	24.1	4.75	0.13	0.51	8	−8.3	−5.8	1516
Boal	DJ-29	9.87	2.02	0.13	0.51	6	−4.4	−1.9	1182
Ancares	DJ-277	13.3	3.16	0.13	0.51	7	−7.9	−5.3	1483
Tojiza	TOJ-5	26.5	4.8	0.13	0,512220	8	−8.2	−5.6	1510
C. Verde	CV-1	34.2	6.66	0.13	0.51	8	−7.7	−5.2	1471
Neira	NE-3 (E)	45.5	10.5	0.13	0.51	7	−2.7	−0.2	1044
Neira	NE-4	39.8	7.75	0.13	0.51	6	−4.1	−1.6	1165
S.Ciprian	VIV-7	29.4	5.99	0.13	0.51	9	−5.5	−3.0	1285
Central Iberian Zone									
Villavieja de Yeltes	LD 6	20.28	4.77	0.14	0.51	12	−6.8	−4.7	1576
Trujillo	LD 8	10.04	2.24	0.1350	0.51	5	−5.3	−2.9	1307
Mérida	LD 9	30.52	6.95	0.14	0.51	5	−3.2	−0.9	1155
Orense	LD 15	21.53	5.270	0.1480	0.51	6	−3.7	−1.8	1372
Traba	LD 16	16.11	5.57	0.21	0.51	6	−0.4	−0.9	–
Caldas de Rei	LD 17	45.04	8.96	0.12	0.51	8	−3.9	−0.9	1012
Braga	LD 18	76.42	12.37	0.1	0.51	7	−9.8	−5.9	1200

population of zircon older than ca. 650 Ma (Fernandez-Suarez et al., 1999; Zeck et al., 2004; Bea et al., 2007; Solá et al., 2008), although the dominant population is younger than ca. 650 Ma.

Similar, older-than-650 Ma zircon, is found in S-type anatectic Variscan granites (Castineiras et al., 2008; Pereira et al., 2008).

Late Neoproterozoic and Paleozoic sedimentary rocks from NW Iberia contain a significant population of detrital zircon in the age ranges ca. 0.65–1.1 Ga, 1.8–2.2 Ga and also in some instances a significant amount of Archaean (ca. 2.5–3.2 Ga) zircons (Nance et al., 2008 and references therein). The relative abundance of these "older" detrital zircon populations is much higher in these sedimentary rocks than in the inherited zircon population of any granitoid (Variscan or pre-Variscan) studied so far. In the early Paleozoic sedimentary rocks the proportion of pre-650 Ma zircons can be as high as ca. 70% (Fernandez-Suarez et al., 2000b; Gutierrez-Alonso et al., 2003; Martinez Catalan et al., 2004) whereas, for example, the proportion of such zircons in the inherited population of Ordovician igneous rocks in the Ollo de Sapo domain (which contain an unusually high proportion of inherited zircon) is less than 35%. And as stated above, the proportion of these older populations is even much more attenuated in the inherited component of late-Variscan granitoids and apparently absent in lower crustal metaigneous granulitic xenoliths.

Many of these Neoproterozoic and pre-Variscan Paleozoic sedimentary rocks have T_{DM} values mostly ranging from ca. 1.4 to 1.9 Ga (Ugidos et al., 1997; Fernandez-Suarez et al., 1999; Castro et al., 2003.

Therefore granitoids that have assimilated significant amounts of this kind of metasedimentary crust (or were produced by its melting) can be expected to contain a significant proportion of pre-Ediacaran zircons as xenocrysts and to have higher than 1.2 Ga T_{DM} values (as is the case in some of the Ollo de Sapo igneous rocks with T_{DM} >1.5 Ga and a significant proportion of pre-650 Ma inherited zircon xenocrysts, (see Montero et al., 2007). However, an apparent contradiction arises here: If the late Variscan granitoids with high T_{DM} values have assimilated that kind of metasedimentary crust, why are pre-650 inherited zircons apparently absent or at least so scarce? A possible explanation could be that the initial melts (either mantle-derived or derived from metaigneous sources) were contaminated by the lower crustal (granulitic) equivalent of these metasedimentary rocks. These lower crustal metasediments have T_{DM} values around 1.7-1-8 Ga ("metapelitic" xenoliths in Villaseca et al., 1999) and do not contain (or contain very little amounts) of pre-650 Ma zircons (Fernandez-Suarez et al., 2006). This idea is consistent with the work of Suarez et al. (1992) on spinel bearing inclusions in late-Variscan granitoids, whose parageneses indicate equilibration with the host magma at temperatures in excess of 800 °C and relatively high pressures. This would suggest that granitoids acquired their "final" Nd isotopic signature in the lower crust.

8.3. General conclusions

The combined observations on the Nd isotopic signatures of granitoids and their zircon inheritance allow the following main conclusions to be extracted:

The main inherited component in late-Variscan granitoids is represented by a population of xenocrystic zircon with late-Neoproterozoic early-Cambrian ages that roughly correspond to tectonothermal events related to the Cadomian orogeny and early Paleozoic ensialic rifting in northern Gondwana (references above) and these ages coincide with the pre-Variscan ages found in the lower crustal granulite xenoliths (Fernandez-Suarez et al., 2006).

The "Cadomian" s.l. metaigneous basement of Iberia (roughly ca. 640–490 Ma) is the most likely source for late-Variscan I-type granitoids. Cadomian igneous protoliths (derived either directly from the ca. 0.9–1.1 Ga SCLM, or through melting of a hypothetical older Neoptoterozoic igneous basement) with little or no crustal (metasedimentary) inheritance would generate, upon melting, granitoids with ca. 1–1.2 Ga T_{DM} values. Contamination of these granitoid magmas with metasedimentary components having high T_{DM} values would generate granitoids with T_{DM} values well in excess of 1.2 Ga.

The apparent dwindling of the pre-Cadomian inherited zircon component through time might indicate that the pre-650 Ma zircon hosted in lower crustal rocks was recycled by melting during the evolution of the Cadomian magmatic arc and the "Ollo de Sapo" voluminous magmatic event. As a result, in late-variscan times, only a fraction of that zircon was available in the lower crust that melted to produce the late-variscan I-type granitoids. The apparent scarcity of pre-Cadomian zircons in late-Variscan I-type granitoids and lower crustal xenoliths could be the end result of a process whereby pre-

Table 3
LA-ICP-MS U–Pb results (inherited zircon).

			Isotopic ratios and 2σ (%) errors						Ages and 2σ absolute errors (Ma)						Reported age (see text for details)		
Anal. #	Sample (pluton)	i.s. [s]	$^{206}Pb/^{238}U$	±2σ	$^{207}Pb/^{235}U$	±2σ	$^{207}Pb/^{206}Pb$	±2σ	$^{206}Pb/^{238}U$	±2σ	$^{207}Pb/^{235}U$	±2σ	$^{207}Pb/^{206}Pb$	±2σ	Age (Ma)	±2σ	Disc %
oc14f13	VV YELTES	21	0.0737	1.98	0.5682	2.46	0.0556	2.02	459	9	457	9	434	46	**458**	**8**	−5.8
oc19g15	ORENSE	15	0.0740	1.86	0.5899	4.72	0.0575	3.14	460	8	471	18	508	68	**459**	**8**	9.4
oc19a15	RICOBAYO	19	0.0754	1.40	0.5978	2.26	0.0569	2.22	469	6	476	9	488	48	**471**	**6**	3.9
oc20e15	CALDAS DE REIS	29	0.0763	1.76	0.5876	3.50	0.0565	3.48	474	8	469	13	470	78	**473**	**8**	−0.9
oc19a05	RICOBAYO	11	0.0764	2.06	0.6182	2.32	0.0584	3.48	475	9	489	9	544	76	**475**	**9**	12.7
oc19h09	TRABA	12	0.0773	2.72	0.6115	4.10	0.0576	4.18	480	13	484	16	514	92	**482**	**11**	6.6
oc15a09	CIPEREZ	20	0.0782	1.30	0.6145	3.60	0.0584	2.76	486	6	486	14	544	60	**485**	**6**	10.7
oc19a06	RICOBAYO	31	0.0785	1.64	0.6267	3.16	0.0570	3.12	487	8	494	12	488	68	**489**	**7**	0.2
oc15b07	CIPEREZ	11	0.0789	2.14	0.6349	2.10	0.0576	1.92	490	10	499	8	514	42	**490**	**10**	4.7
oc15a16	CIPEREZ	14	0.0794	1.60	0.6515	3.24	0.0595	3.04	493	8	509	13	584	66	**493**	**8**	15.6
oc15a15	CIPEREZ	11	0.0815	2.20	0.6316	4.66	0.0562	3.22	505	11	497	18	460	72	**507**	**10**	−9.8
oc15a14	CIPEREZ	17	0.0831	1.26	0.6524	4.16	0.0584	3.06	514	6	510	17	544	68	**514**	**6**	5.5
oc19a16	RICOBAYO	9	0.0833	4.60	0.7026	8.66	0.0607	6.04	516	23	540	36	628	132	**516**	**23**	17.8
oc14f15	VV YELTES	9	0.0835	3.20	0.6880	3.40	0.0596	3.02	517	16	532	14	586	66	**517**	**16**	11.8
oc15b05	CIPEREZ	14	0.0835	2.02	0.6705	3.62	0.0580	2.56	517	10	521	15	528	56	**517**	**10**	2.1
oc14g08	VV YELTES	52	0.0845	3.60	0.7109	6.96	0.0597	13.32	523	18	545	72	592	288	**519**	**15**	11.7
oc15b09	CIPEREZ	30	0.0849	1.76	0.6885	2.36	0.0592	2.16	525	9	532	10	574	46	**528**	**8**	8.5
oc14f10	VV YELTES	21	0.0854	1.70	0.7014	2.42	0.0595	2.56	528	9	540	10	586	56	**528**	**9**	9.9
oc15b14	CIPEREZ	20	0.0853	1.52	0.7056	3.94	0.0598	3.38	528	8	542	17	596	74	**528**	**8**	11.4
oc19b16	RICOBAYO	9	0.0854	2.04	0.7138	4.72	0.0601	3.90	529	10	547	20	606	84	**529**	**10**	12.7
oc22c12	VV YELTES	13	0.0859	2.02	0.6637	4.92	0.0581	3.78	531	10	517	20	532	84	**531**	**10**	0.2
oc14g06	VV YELTES	24	0.0861	1.20	0.7036	1.94	0.0591	1.68	533	6	541	8	570	36	**533**	**6**	6.5
oc21h05	EL MIRON	16	0.0866	1.80	0.6977	2.50	0.0589	1.90	535	9	537	10	562	40	**536**	**9**	4.8
oc15b15	CIPEREZ	15	0.0869	1.42	0.6883	3.36	0.0580	2.38	537	7	532	14	530	52	**539**	**7**	−1.3
oc14f05	VV YELTES	16	0.0870	1.56	0.7159	3.86	0.0595	1.98	538	8	548	16	584	42	**536**	**8**	7.9
oc15b10	CIPEREZ	24	0.0870	1.24	0.7096	2.44	0.0590	2.64	538	6	544	10	566	58	**539**	**6**	4.9
oc14e07	VV YELTES	28	0.0873	1.06	0.7105	2.26	0.0586	1.46	539	5	545	10	552	32	**537**	**5**	2.4
oc15a06	CIPEREZ	20	0.0878	1.54	0.7120	2.52	0.0591	2.38	542	8	546	11	568	52	**543**	**8**	4.6
oc22d07	VV YELTES	19	0.0878	2.24	0.7265	2.98	0.0595	2.52	543	12	555	13	584	56	**543**	**12**	7.0
oc14g13	VV YELTES	29	0.0884	1.56	0.7064	2.54	0.0581	2.36	546	8	543	11	532	52	**545**	**8**	−2.6
oc15a10	CIPEREZ	24	0.0884	1.68	0.7417	3.86	0.0605	3.44	546	9	563	17	620	74	**546**	**9**	11.9
oc14e10	VV YELTES	26	0.0887	1.20	0.7353	2.94	0.0598	2.40	548	6	560	13	596	52	**548**	**6**	8.1
oc22c13	VV YELTES	17	0.0887	3.00	0.7252	3.82	0.0599	5.18	548	16	554	16	598	112	**550**	**15**	8.4
oc14c12	LA ALBERCA	18	0.0895	2.04	0.7245	6.54	0.0595	5.08	553	11	553	28	582	110	**552**	**9**	5.0
oc15a05	CIPEREZ	30	0.0896	1.20	0.7221	1.78	0.0589	1.68	553	6	552	8	562	38	**553**	**6**	1.6
oc23a09	CIPEREZ	20	0.0896	1.58	0.7284	3.26	0.0589	3.50	553	8	556	14	562	78	**554**	**8**	1.6
oc14f06	VV YELTES	15	0.0898	1.44	0.7268	2.98	0.0592	2.10	555	8	555	13	574	46	**554**	**8**	3.3
oc14e11	VV YELTES	42	0.0912	1.34	0.7450	2.22	0.0588	1.32	563	7	565	10	558	28	**562**	**7**	−0.9
oc14f16	VV YELTES	15	0.0912	1.32	0.7480	2.68	0.0584	2.32	563	7	567	12	542	50	**563**	**7**	−3.9
oc13b12	LINARES	13	0.0931	2.72	0.7906	2.20	0.0617	2.50	574	15	592	10	664	54	**574**	**15**	13.6
oc19j10	ORENSE	23	0.0933	1.10	0.7527	2.58	0.0590	1.74	575	6	570	11	566	38	**577**	**5**	−1.6
oc14g11	VV YELTES	17	0.0936	1.14	0.7852	3.76	0.0608	2.60	577	6	588	17	630	56	**575**	**6**	8.4
oc22c14	VV YELTES	16	0.0945	1.58	0.7880	4.18	0.0623	2.12	582	9	590	19	684	46	**581**	**8**	14.9
oc19b06	RICOBAYO	21	0.0949	2.30	0.8069	5.00	0.0614	4.50	584	13	601	23	652	96	**586**	**13**	10.4
oc19g10	ORENSE	17	0.0951	2.04	0.8003	3.70	0.0612	2.02	586	11	597	17	646	44	**586**	**11**	9.3
oc14e14	VV YELTES	16	0.0960	1.36	0.7814	1.62	0.0589	1.28	591	8	586	7	562	28	**588**	**7**	−5.2
oc14g12	VV YELTES	23	0.0997	1.84	0.8455	3.68	0.0610	2.64	613	11	622	17	640	58	**611**	**11**	4.2
oc13a05	PONFERRADA	28	0.0999	1.06	0.8332	2.14	0.0614	1.90	614	6	615	10	650	42	**614**	**6**	5.5
oc19g09	ORENSE	31	0.1003	2.12	0.8398	4.24	0.0601	3.50	616	12	619	20	608	74	**616**	**12**	−1.3
oc14d08	LA ALBERCA	31	0.1007	1.32	0.8259	1.60	0.0598	1.20	619	8	611	7	596	26	**619**	**8**	−3.9
oc19b07	RICOBAYO	16	0.1010	1.68	0.8405	1.42	0.0629	2.08	620	10	619	7	702	44	**619**	**7**	11.7
oc15f14	MERIDA	26	0.1021	2.44	0.8838	6.86	0.0606	5.62	627	15	643	33	624	122	**624**	**14**	−0.5
oc19g13	ORENSE	15	0.1025	2.80	0.8253	4.18	0.0593	2.14	629	17	611	19	578	46	**622**	**15**	−8.8
oc19j14	ORENSE	24	0.1032	1.76	0.8856	3.44	0.0632	3.48	633	11	644	16	712	72	**636**	**10**	11.1
oc19c15	RICOBAYO	11	0.1040	2.54	0.9207	3.98	0.0635	3.26	638	15	663	19	724	70	**638**	**15**	11.9
oc22c05	VV YELTES	21	0.1057	1.58	0.8838	2.20	0.0605	2.30	648	10	643	10	622	50	**646**	**8**	−4.2
oc14g16	VV YELTES	44	0.1108	1.12	0.9439	1.22	0.0617	1.10	678	7	675	6	664	24	**676**	**6**	−2.1
Discordant analyses (pre-650 Ma)																	
oc22d15	VV YELTES	32	0.0840	4.90	1.0606	4.20	0.0933	3.50	520	25	734	22	1492	66			
oc19b14	CIPEREZ	36	0.0934	1.90	0.8522	3.60	0.0666	3.60	575	8	626	15	824	76			
oc14g14	LA ALBERCA	25	0.4904	1.50	13.0925	3.22	0.1934	1.00	2572	40	2686	21	2770	12			

i.s. = signal interval integrated for isotope-ratio and age calculation (in seconds).
disc% = percent discordance calculated from $^{207}Pb/^{206}Pb$ and $^{206}Pb/^{238}U$ ages (negative values: reversely discordant analyses).

Cadomian zircons have been consumed in earlier stages of melting (late Neoproterozoic, Cambrian and Ordovician magmatic events) of the lower crust (see also Fernandez-Suarez et al., 2006).

Finally, it ought to be said that a more comprehensive study of zircon inheritance in late Variscan granitoids and mafic rocks is necessary in order to further test the above ideas.

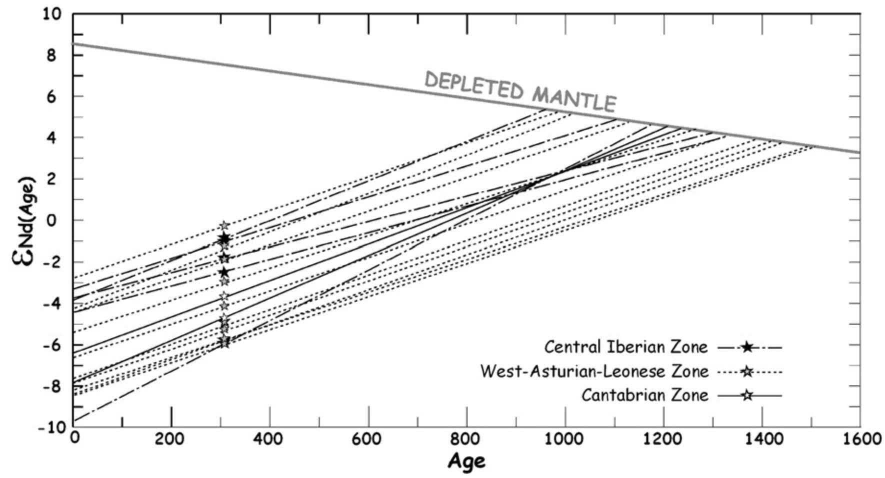

Fig. 6. Age vs. ε_{Nd} diagram. Stars are grey coded as in Fig. 2.

Supplementary materials related to this article can be found online at doi:10.1016/j.lithos.2010.09.010.

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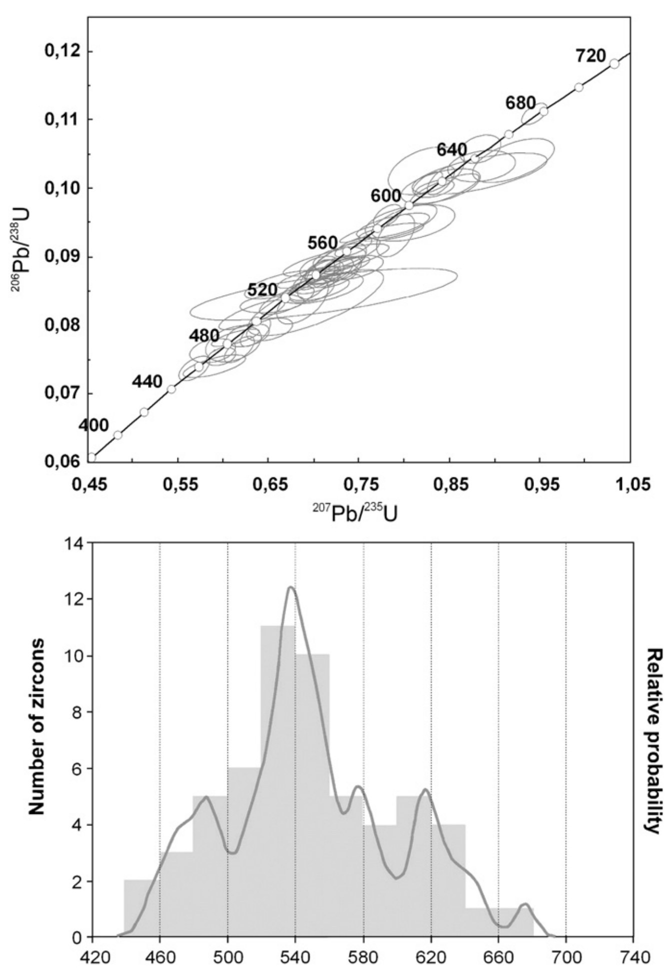

Fig. 7. Concordia plot and probability density histogram for inherited zircon ages (three pre-650 Ma analyses not included).

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