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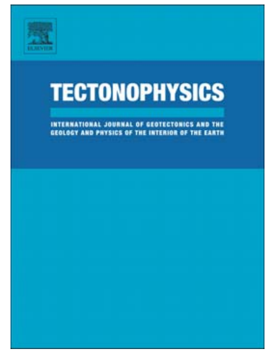

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Tracing the Cambro-Ordovician ferrosilicic to calc-alkaline magmatic association in Iberia by in-situ U–Pb SHRIMP zircon geochronology (Gredos massif, Spanish Central System batholith).

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ABSTRACT

U-Pb geochronological study of zircons from nodular granites and Qtz-diorites comprising part of Variscan high-grade metamorphic complexes in Gredos massif (Spanish Central System batholith) points out the significant presence of Cambro-Ordovician protoliths among the Variscan migmatitic rocks that host the Late Carboniferous intrusive granitoids. Indeed, the studied zone was affected by two contrasted tectono-magmatic episodes, Carboniferous (Variscan) and Cambro-Ordovician. Three main characteristics denote a close relation between the Cambro-Ordovician protholiths of the Prado de las Pozas high-grade metamorphic complex, strongly reworked during the Variscan Orogeny, and other Cambro-Ordovician igneous domains in the Central Iberian Zone of the Iberian Massif: 1) Geochemical features show the ferrosilicic signature of nodular granites. They plot very close to the average analysis of the metavolcanic rocks of the Ollo de Sapo formation (Iberia). Qtz-diorites present typical calc-alkaline signatures and are geochemically similar to intermediate cordilleran granitoids. 2) Both Qtz-diorite and nodular granite samples yield a significant population of Cambro-Ordovician ages, ranging between 483 and 473 Ma, and 487 and 457 Ma respectively. Besides, 3) the abundance of zircon inheritance observed on nodular granites matches the significant component of inheritance reported on Cambro-Ordovician metagranites and metavolcanic rocks of central and NW Iberia.

The spatial and temporal coincidence of both peraluminous and intermediate granitoids, and specifically in nodular granites and Qtz-diorite enclaves of the Prado de las Pozas high-grade complex is conducive to a common petrogenetic context for the formation of both magmatic types. Tectonic and geochemical characteristics describe the activity of a Cambro-Ordovician arc-back-arc tectonic setting associated with the subduction of the Iapetus-Tornquist Ocean and the birth of the Rheic Ocean. The extensional setting is favorable for the generation, emplacement and fast rise of subduction related cold diapirs, supported by the presence of typical calc-alkaline cordilleran granitoids contemporary with ferrosilicic volcanism.

Keywords: Cambro-Ordovician, High-grade metamorphic complexes, Nodular granites, Ferrosilicic magmatism, U–Pb zircon dating, North-Gondwana.

1.- Introduction

The European Variscan Chain resulted from the closure of the Rheic Ocean and the ensuing collision of Gondwana and Laurussia (Matte, 1991; Martínez Catalán et al., 2007, Nance et al., 2010). In NW Iberian Massif, several allochthonous complexes are thrust onto parautochthonous and autochthonous terranes (western part of the European Variscan Chain; e.g., Martínez Catalán et al., 2002). These terranes belong to the North-Gondwana margin (e.g., Martínez Catalán et al., 2002, 2007; Abati et al., 2007; Díez Fernández et al., 2010, 2012a). The pre-Variscan Paleozoic evolution of this tectonic realm includes the formation of a Cambro-Ordovician peri-Gondwanan magmatic arc presumably linked to the subduction of the Iapetus-Tornquist Ocean, and simultaneous opening of the Rheic Ocean triggered by back-arc extension and rifting (e.g., van Staal et al., 1998; Abati et al., 1999, 2007; Winchester et al., 2002; Stampfli and Borel, 2002; Fernández-Suárez et al., 2003; Fuenlabrada et al., 2010; Sánchez Martínez et al., 2012; Díez Fernández et al., 2012b). The analysis of the Cambro-Ordovician magmatism in the Iberian Massif is essential to properly understand the building of the arc and its bearing on the inception of the Rheic Ocean. This widespread magmatism along the northern Gondwana margin comprises rift-related mafic rocks: continental tholeiites (Murphy et al., 2008) and N-MORB, E-MORB and OIB basalts (Sánchez-García et al., 2010), alkaline to peralkaline granites (Pin et al., 1992; Díez Fernández et al., 2012b, 2015), and silicic peraluminous volcanic and plutonic rocks (e.g., Fernández et al., 2008, Díez Montes et al., 2010). These silicic rocks have been associated with the onset of rifting and the formation of migmatites and a core-complex setting in the middle crust (e.g., Fernández et al., 2008, Díez Montes et al., 2010). Nevertheless, Cambro-Ordovician magmatism with intermediate composition (60% SiO_2), with a meaningful calc-alkaline signature, is well represented in the Iberian Massif (e.g., Rubio-Ordóñez et al., 2012) in association with voluminous silicic volcanism. This suggests a long-lived subduction active margin prior to and/or during rifting (Díez Montes et al., 2010; Dias da Silva et al., 2014, 2015).

During the past decade, many Variscan metaigneous domains of the Central Iberian Zone (central part of the Iberian Massif) have been ascribed to a late Cambrian to Middle Ordovician (ca. 500-460 Ma) long lasting magmatic event that occurred in North-Gondwana margin (Fig. 1a, Table 1): 1) the so-called "Ollo de Sapo" Formation (Hernández Sampelayo, 1922; Parga Pondal et al., 1964; Martínez Catalán et al., 2004), the best known and most voluminous unit adscribed to Cambro-Ordovician magmatism (Fernández et al., 2008) dated at 495-470 Ma (e.g., Montero et al., 2007, 2009); 2) the pre-Variscan magmatism occurring at the Schist and Greywacke Complex (SGC) Domain, (Valverde and Dunning, 2000; Bea et al., 2003; Zeck et al. 2004), composed mostly of 498-462 Ma metagranites (Montero et al., 2007; Talavera, 2009; Talavera et al., 2013), and 482-470 Ma tonalite–granodiorite igneous bodies to the south (the Beira Baixa-Central Extremadura belt, 482-470 Ma, Antunes et al., 2009; Romão et al., 2010; Rubio-Ordóñez et al., 2012); and 3) the 495-480 Ma volcaniclastic rocks from the Urra Formation and the 493-471 Ma Portalegre granite and Carrascal granite and related gabbros and diorites, in the boundary between the Central Iberian and the Ossa-Morena zones (Solá et al., 2008 and references therein). In addition, a fragment of a Cambro-Ordovician magmatic arc of peri-Gondwanan affinity has been described for the uppermost allochthonous units of the NW Iberian Massif (Abati et al., 1999, 2007; Castiñeiras et al., 2010; Díaz García et al., 2010), and similar associations of Late Ordovician (455±2 Ma) aluminous and metaluminous plutonic rocks, calc-alkaline ignimbrites and epiclastic volcanic rocks have been presented in the northeastern Iberian Peninsula (Álvaro et al., 2008; Murphy et al., 2008; Navidad et al., 2010).

The tectonic scenario drawn by the structural configuration and the geochemical features of Cambro-Ordovician metaigneous domains suggests back-arc extension and rifting in the active continental margin of North-Gondwana (e.g., Arenas et al., 2007; Fernández et al., 2008; Rubio-Ordóñez et al., 2012). Petrogenetically, this back-arc setting, represented by the northern part of the Central Iberian Zone (Ollo de Sapo Domain, Fig. 1a), as well as the basal allochthonous units of NW Iberia (Díez Fernández et al., 2010; Dias da Silva et al., in press), is defined by volcanic belts with high iron and silica contents for very low contents in calcium, crustal isotopic signatures, and a large amount of inherited restitic zircons, interpreted as resulting from a process of almost total melting of subducted sedimentary rocks (fertile material) relaminated in the base of the crust (≈

1000 ° C and 1.5-2 GPa) (Castro et al., 2009, 2013; Talavera, 2009). In turn, the Beira Baixa-Central Extremadura tonalite-granodiorite belt (southern part of the SGC Domain, Fig. 1a) is composed of I-type calc-alkaline intrusive bodies, which suggests that it represents an outward continental magmatic arc relative to the Ollo de Sapo continental back-arc setting (Rubio-Ordóñez et al., 2012). Cambro-Ordovician igneous ages have also been reported for the northern part of the SGC Domain. Orthogneisses (Castilian gneisses, in the sense of Talavera et al., 2013) exposed in the northern part of the Gredos massif, among other places, where recently dated at 498-488 Ma (Talavera et al., 2013).

Coupled petrological–thermomechanical numerical models (Paterson et al., 2011; Vogt et al., 2012) estimate the rates and volumes of magmatic addition expected in active continental margins. The tectonic setting determines the ascent and composition of liquids generated during subduction processes. In extensional settings, the backward motion of the subduction zone leads to necking and rifting processes of the overriding plate. Therefore, large volumes of mafic magmas are formed in the back-arc region (Vogt et al., 2012), whereas the relamination in the crust-mantle or lithosphere-asthenosphere boundary by partially molten cold diapirs, rooted at the subduction channel, possibly determines the formation of an intermediate to felsic magmatic arc (Gerya and Yuen, 2003; Castro and Gerya, 2008; Castro et al., 2010, 2013a; Hacker et al., 2011). Experimental studies carried out in hybrid plumes (subducted sediments and basalts) constrain the conditions and composition of the plume source-for the off-crust generation of intermediate magmas (Castro et al., 2010, 2013b), setting the main characteristics of cordilleran magmatism in active continental margins, which are comparable to those proposed for the origin of ferrosilicic volcanism described in Iberia (Castro et al., 2009).

In the central part of the Gredos massif (Fig. 1b), the genesis of high-grade metamorphic complexes and associated magmatic rocks have been mostly ascribed to Carboniferous processes (Variscan orogeny) despite the limited amount of available radiometric data. In this work, a high-grade metamorphic complex, located in the central part of the Gredos massif (Spanish Central System batholith), is described with the aim of discussing whether or not it represents an older igneous or metamorphic event. U-Pb zircon ages and geochemical features attest an igneous-derived Cambro-Ordovician origin for these Variscan high-grade metamorphic rocks, further expanding the extent and volume of the reported magmatism for this critical tectonic period in the North-Gondwana margin, and pointing possible clues for understanding the close spatial and temporal relationship between the calc-alkaline intermediate and peraluminous silicic magmatism in lower Paleozoic times.

2.- Geological setting

2.1 Ordovician magmatism in the Central Iberian Zone of the Iberian Massif

Early Cambrian to Middle Ordovician igneous and sedimentary rocks, variably metamorphosed during the Variscan cycle (with grade increasing roughly from East to West), together with Variscan granitoids, are well-represented in the Central Iberian Zone of the Iberian Massif. The characterization and interpretation of this magmatism and its tectonic evolution during Cambro-Ordovician times in the North-Gondwana margin have been progressively understood in spite of the extensive Variscan deformation and metamorphism. The Cambro-Ordovician igneous rocks are mainly exposed along three major lineaments: the Ollo de Sapo Domain, the SGC Domain, and the Urra-Portalegre Domain (Fig. 1a).

2.1.1 Ollo de Sapo Domain

The 600 km long Ollo de Sapo Domain includes a variably metamorphosed magmatic association of plutonic, subvolcanic and eruptive facies (Ollo de Sapo Formation) located to the north and central east of the Iberian Massif (Fig. 1a) (Fernández et al., 2008; Montero et al., 2007; Díez Montes et al., 2010). These igneous rocks are characterized by Al saturation index ASI >1, FeO >2.5 wt.%, MgO >0.8 wt.%, for very low contents in calcium (CaO <2.0 wt.%) (Castro et al., 2009) (Table 2, see extended geochemical features in section 4).

The Ollo de Sapo metavolcanic rocks show strong HREE fractionation supporting high-pressure source conditions. Up to 900 °C and 1.0 to 1.1 GPa have been reported for the felsic xenoliths that may represent the lower crust composition in Iberia, and the high-pressure equivalent of Neoproterozoic metagreywackes forming the pre-Variscan basement (SGC Domain) (Villaseca et al., 1999; Fernández et al., 2008). Isotopic compositions of ferrosilicic magmas of the Ollo de Sapo Formation show a narrow variation in Sr–Nd isotopes compared with the Neoproterozoic sediments. $^{87}Sr/^{86}Sr$ initial ratios are between 0.707 and 0.713, and εNd between -5.8 and -3.3 (490-485 Ma) (Fernández et al., 2008; Talavera, 2009). This isotopic signature could be explained by the averaging effect of melting of these heterogeneous protoliths resulting in more homogeneous magmas (Fernández et al., 2008).

The Ollo de Sapo volcanism has been dated between 495±5 and 483±3 Ma (Cambro-Ordovician), followed by an intrusive stage that lasted from 483±3 to 474±4 Ma (Early Ordovician) (Montero et al., 2007) (Table 1). Both meta-effusive and intrusive rocks show an extremelly high proportion (70–80 %) of inherited zircons and zircon cores (Montero et al., 2007; Talavera et al., 2013).

2.1.2 Schist and Greywacke Complex (SGC) Domain: Northern and southern (Beira Baixa-Central Extremadura belt) parts

Parallel to the boundary with the Ollo de Sapo Domain, the northern part of the North SGC Domain contains small Cambro-Ordovician metagranite bodies that are exposed in the Tormes Dome, the Gredos and Guadarrama sectors (Talavera et al., 2013) (Fig. 1a). They are peraluminous and alkali-calcic to calc-alkaline magmas and do not show any significant chemical difference from the rocks of the Ollo de Sapo Formation (Talavera, 2009) (Table 2). Isotopic compositions and geochronological features are identical to those described above for the Ollo de Sapo Formation.

At the southern part of the SGC Domain, the Beira Baixa–Central Extremadura tonalite–granodiorite belt extends for more than 250 km (Fig. 1a). It represents a tonalite–granodiorite calc-alkaline suite intruded in the SGC basement, which resembles a continental magmatic arc (Rubio-Ordoñez et al., 2012). The available U–Pb ages (Antunes et al. 2009; Neiva et al. 2009; Rubio-Ordoñez et al., 2012), obtained from intrusive tonalites and granodiorites, between 482 and 470 Ma (Early Ordovician), are contemporary with the predominantly metaplutonic rocks and volcanic lower Cambrian to Middle Ordovician formations located northwards in the Central Iberian Zone (Table 1).

2.1.3 Urra-Portalegre Domain

The magmatic rocks of the Urra-Portalegre Domain mainly consist of Early Ordovician felsic, porphyritic volcaniclastic rocks. This domain is located in the transition between the Central Iberian and Ossa-Morena zones (SW Iberian Massif) (Fig. 1a) (Solá et al., 2008). Volcanic rocks have rhyolitic to dacitic compositions, are peraluminous and are associated with calc-alkaline granitoids, diorites and gabbros of the same age. $^{87}Sr/^{86}Sr$ initial isotopic signatures range between 0.709 and 0.719, with more restricted εNd (−2.65 to −0.35) (495-470 Ma) (Solá et al., 2008). SHRIMP U-Th-Pb geochronology yields $^{206}Pb/^{238}U$ Cambrian ages ranging from 494.6±6.8 Ma to 488.3±5.2 Ma for the Urra formation (Solá et al., 2008). In this domain, U-Pb ages yield 493-471 Ma (Cambro-Ordovician) for the Portalegre granite, the Carrascal granites and related gabbros and diorites (Solá et al., 2008) (Table 1).

2.2 Gredos massif (Spanish Central System batholith)

The Variscan Spanish Central System batholith (e.g., Moreno-Ventas et al., 1995; Castro et al., 2002), with more than 300 km in length and 60 km in width, provides an almost continuous granite exposure in the Central Iberian Zone (Fig. 1a). Zircon geochronology of granitoids and mafic igneous rocks of the Spanish Central System batholith and nearby regions yielded an age range of around 320 to 295 Ma, mostly contemporary with or later than the regional, Variscan D3 deformation phase (see age compilation in Díaz-Alvarado et al., 2013). The Gredos massif, located at the central part of the Spanish Central System batholith (Fig. 1b), is composed of granodiorites to monzogranites, which constitute more than 90 vol.% of the intrusive rocks. Minor amounts of gabbro to Qtz-diorite are present in the batholith. In general, all plutonic rocks from gabbros to granodiorites form a typical K-rich, calc-alkaline association (Moreno-Ventas et al., 1995) having close similarities with typical Caledonian I-type batholiths (Chappell and Stephens, 1988), and they belong to the large group of intrusives catalogued as "granodiorites" or "calc-alkaline series granitoids" in regional syntheses and classifications of the Paleozoic magmatism of Iberia (Capdevila et al., 1973; Castro et al., 2002). However, significant differences can be observed among and inside intrusive granitoid bodies, including variable Crd contents and inherited zircons extracted from metasedimentary rocks. These heterogeneities have been interpreted as caused by the interaction (mainly assimilation processes) between the magma and its host rocks (Díaz-Alvarado et al., 2011).

One of the most distinctive features of the Spanish Central System batholith is the presence of upper crustal migmatites with associated anatectic granites (S-type; according to the original definition of Chappell and White, 1974). Metasedimentary rocks occur as large tabular septa, several km in length, and as xenoliths to the scale of a few centimeters to hundreds of meters. Most of these migmatites are derived from pelitic and semipelitic metasedimentary rocks that form part of a several km-thick Neoproterozoic-Cambrian turbiditic series (Rodríguez Alonso et al., 2004).

The metamorphic peak and migmatization in the area occupied by the Spanish Central System batholith took place between 337 and 316 Ma (middle Carboniferous) (e.g., Castiñeiras et al., 2008; Escuder Viruete et al., 1998). PT determinations in the anatectic complexes of the Spanish Central System batholith yielded around 0.4 GPa and 750 °C (middle crust) for the migmatitic conditions (Pereira, 1993; Pereira and Bea, 1994). The general structure of the Spanish Central System batholith in the studied area of the Gredos massif is that of a layered intrusive complex, with distinct magma batches that successively intruded a migmatitic crust (Yenes et al., 1999; Díaz-Alvarado et al., 2013). The emplacement of these tabular magma bodies profited large extensional shear zones affecting the migmatitic host rocks, while U-Pb-Th zircon geochronology of granitoids and mafic igneous rocks of the Spanish Central System batholith and nearby regions reveals that most of the magmatism occurred at 320-295 Ma, as indicated above (e.g., Díaz-Alvarado et al., 2012, 2013; Gutiérrez-Alonso et al., 2011).

Las Pozas high-grade metamorphic complex (Fig. 1b, c) is included in the Gredos massif as a part of the upper and middle crust host-rocks of intrusive late-Variscan granitoids. Nodular granites and nebulites in the central Gredos massif (Fig. 1b, c) define an approximately 5 km in length and 2 km in width elongated, lenticular body limited by the intrusive Variscan granodiorite sheets of Circo de Gredos and Las Pozas, dated at ca. 313 and ca. 304 Ma, respectively (Díaz-Alvarado et al., 2011, 2103). The granitoid sheets show a magmatic foliation defined by the orientation of the preferred orientation of Kfs megacrysts (abbreviations by Kretz, 1983), the parallel arrangement of enclave corridors, schlieren, xenolith septa and igneous leucocratic veins. On the other hand, the metamorphic complex shows a preferred NE-SW orientation defined by sets of restites, nodules, enclaves and leucogranitic lobes, which make a complex nebulitic macrostructure. These sets are present in major contacts between nebulite and nodular granite domains, and may host decimeter-scale shear zones. At the top of the nebulites, nodular granites show magma-magma contacts with intrusive granodiorites (Fig. 1c). A SE-dipping migmatitic folation can be observed in the Las Pozas metamorphic complex, which is sub-parallel to the bulk orientation of the complex and to its external contacts with the intruded granitoid sheets (Fig. 1).

3.- Sampling strategy, field relations and petrography.

3.1 Sampling strategy

Five samples were collected at Prado de las Pozas (Fig. 1c) in order to describe and analyze the geochemical characteristics of the different magmatic and metamorphic rock associations that occur in this high-grade metamorphic complex (Table 2). Due to the close spatial and textural relation between nebulites (J809-10) and nodular granites (J706-43), only the latter were selected for a geochronological study, together with Crd-rich leucogranitic segregates (J809-15) and Qtz-dioritic enclaves (J809-13) (Table 3), in order to clarify their complex intrusive relations.

3.2 Nodular granites and nebulites with Bt-Crd-Sil enclaves

Nodular granites and nebulites with Bt-Crd-Sil enclaves show transitional contacts (although in Fig. 1c they are separated by a continuous layer of Crd-leucgranites) and are mainly melanocratic, heterogeneous rocks (Fig. 2), containing felsic Crd-rich segregates (Fig. 2a), Bt-Crd-Sil restites (Fig. 2b, c) and Kfs nodules (Fig. 2d). Nodular granites are present at the top contact with Las Pozas Bt-granodiorite sheet (Fig. 1c, 2e), where they show abundant Kfs nodules 8-10 cm in diameter (Fig. 2d). Restite alignments, schlierens and other structural markers describe a N30-60E trending and SE dipping foliation, which is identical to the orientation of the main contacts and to the ductile-brittle shear zones present in nebulites (Fib. 1c). Two distinct nebulite facies constitute most of the high-grade complex (Fig. 1c): a coarse-grained facies, with scarce restites and rich in Kfs nodules; and a medium- to fine-grained facies, rich in restites and leucogranitic segregates (Fig. 2b). Restites, consisting of aggregates of Bt, Crd and Sil, are abundant but heterogeneously distributed (Fig. 2c). Mafic enclaves of quartz-diorite (Fig. 2f), refractory Qtz-nodules and quartzites, and ellipsoidal enclaves of phlebitic migmatite are abundant mostly in nebulites.

Both nebulites and nodular granites consist mainly of anhedral Qtz with undulose extinction, subhedral Bt (Mg#=40-48), subhedral Pl that shows normal zonation with cores of andesine (≈An32) rimmed by an inner band of oligoclase (≈An21) and an outer band of albite (≈An4), subhedral Kfs with perthitic textures, anhedral and subhedral grains of Crd (Mg#=60) and fibrolitic Sil. The main accessory minerals are Ilm, Ap, Tur and Zrn.

3.3 Crd-Leucogranites

Leucocratic granites constitute a continuous sheet at the center of the studied exposure in Prado de las Pozas, central Gredos massif (Fig. 1c) and form lobulate enclaves or lobes within nebulites (Fig. 1c and Fig. 2a). Their most outstanding feature is the presence of abundant, irregularly shaped, Crd cumulates that show a preferred orientation according to the main foliation (Fig. 1c), with no evidence of solid-state structures.

The mineral assemblage consists of rounded Qtz crystals, subhedral grains of Kfs, subhedral Pl grains showing normal zonation (≈An16-3), subhedral grains of Bt (Mg#=36-42) and Crd (Mg#=53-55), which usually contains abundant, small, drop-like inclusions of Qtz. The accessory mineral assemblage consists mainly of Ap and Zrn.

3.4 Mafic rocks

Qtz-dioritic enclaves included within the nebulites (Fig. 2f) and Crd-leucogranites are similar to the mafic microgranular enclaves that are widespread in all types of Carboniferous intrusives in the Gredos massif (e.g., Moreno-Ventas et al., 1995; Bea et al., 1999; Díaz-Alvarado et al., 2011). They are variably sized and shaped, present lobulate contacts with the nebulites, and are commonly clustered in some areas. Moreover, mafic enclaves are also found in leucogranite layers, showing elliptical contour and absence of solid-state fabrics (Fig. 2f).

They are composed of Pl phenocrysts with complex oscillatory zoning (≈An65-32), Qtz and Bt (Mg#=31-40). They also contain domains rich in calcic amphibole as either isolated crystals or polycrystalline aggregates. Accessory minerals are Ilm, Ap and Zrn.

4.- Geochemistry.

Five samples from the high-grade complex of Prado de las Pozas were crushed and milled to very fine powder in steel cups. Whole-rock chemistry of major elements and Zr was analyzed by X-ray fluorescence (XRF) at the University of Oviedo (Spain) using glass beads. Precision of the XRF technique was better than ±1.5% relative. Trace elements, including rare earth elements (REE), were analyzed by inductively coupled plasma mass spectrometry (ICP-MS) with an HP-4500 system at the University of Huelva (Spain), following digestion in an HF + HNO_3 (8:3) solution, drying and further second dissolution in 3 ml HNO_3. The average precision and accuracy for most of the elements were determined by repeated analyses of the SARM-1 (granite) and SARM-4 (norite) international rock standards, and are in the range 5–10% relative.

The results of geochemical analyses are represented in Table 2 and Figure 3. Samples J706-43 (nodular granite), J809-10 (nebulite) and J809-13 (Qtz-diorite) were previously included in a geochemical characterization of the Gredos massif (Díaz-Alvarado et al., 2011).

The composition of the nodular granite is very close to the average analysis of the metavolcanic rocks of the Ollo de Sapo Formation (Iberia). This means a high FeO content in relation to very low CaO (FeO = 3.85 and CaO = 0.87 wt%, Fig. 3a, c, d), moderately peraluminous, Al saturation index ASI = 1.52 (Fig. 3b), and MgO rich (MgO = 1.37 wt.%; Fig. 3c, d). These geochemical features have led some authors to consider them as ferrosilicic rocks (Fernández et al, 2008; Castro et al., 2009). Furthermore, metasedimentary phlebitic enclaves included in the high-grade complexes are geochemically very close to the average composition of Neoproterozoic metagreywackes of the SGC Domain (Table 2), while heterogeneous nebulitic rocks have intermediate characteristics between geochemical signatures of the Ollo de Sapo and SGC domains (Fig. 3).

The Crd-leucogranite is characterized for their exceptionally high FeO contents (FeO = 1.96 wt.%, Table 2) for a high silica (rhyolitic) magma; they are projected very close to the Miranda do Douro and the Antoñita gneisses (Ollo de Sapo Formation) and to the porphyritic volcaniclastic rocks of the Urra formation (Fig. 3c, e).

Instead, Qtz-diorite enclaves belong to the typical calc-alkaline associations of cordilleran granitoids (Fig. 3d, e). No geochemical link between Qtz-diorites and nodular granites or nebulites is observed despite their spatial and temporal relationship.

5.- SHRIMP U-Th-Pb geochronology

5.1 Analytical techniques

Zircon separation was carried out at the laboratories of the University of Huelva, using classical procedures including magnetic (Frantz) and density separation. Sample J706-43 (nodular granites) was analyzed with the SHRIMP II (sensitive high resolution ion microprobe) at the Research School of Earth Sciences (Australian National University, Canberra). The non-magnetic, heavy mineral concentration was hand-picked in order to classify and group zircon crystals on the basis of shape, size and lack of fractures or inclusions. The selection of the zircons was random to ensure that all the possible zircon populations are represented. Zircon grains were mounted in epoxy resin together with zircon standards SL13 (U = 238 ppm) and TEMORA ($^{206}Pb/^{238}U$ = 0.06683). The same procedure was carried out for samples J809-13 and J809-15 (Qtz-diorite enclaves and Crd-leucogranite segregates, respectively), which were analyzed in the SHRIMP II instrument at Beijing-SHRIMP Center (Chinese Academy of Geological Sciences, Beijing). The mounts were polished to expose the grain interiors, photographed at high magnification in transmitted and reflected light microscopes and imaged by SEM (scanning electron microscope) (backscattered and cathodoluminescence images) to document the internal growth zoning, inclusions and fractures of the grains. They were then cleaned and coated with high-purity Au in preparation for analysis. Selected areas in zircon grains were analyzed for U, Th and Pb isotopes on both SHRIMP II instruments (RSES: Research School of Earth Sciences, Canberra, and Beijing-SHRIMP Center), using a procedure similar to that described by Williams and Claesson (1987). A 10 kV negative O_2 primary beam was focused to ca. 20 μm diameter. Positive secondary ions were extracted at 10 kV and mass analyzed at ca. R5000 mass resolution on a single ETP secondary electron multiplier by peak stepping through the isotopes of interest. Analytical uncertainties are 1σ precision estimates. All the analyses listed and plotted were corrected for common Pb using the measured ^{204}Pb and a common Pb composition appropriate to the age of each spot (Cummings and Richards, 1975). Concordia ages have been calculated with ISOPLOT 3.0 software (Ludwig, 2003). Uncertainties are 95% confidence limits (tσ, where t is the student's t multiplier) and include the uncertainty in the Pb/U calibration (0.3–0.5%).

5.2 U-Th-Pb geochronology results

Zircon populations extracted from the nodular granite (J706-43), the Qtz-dioritic enclave (J809-13) and the Crd-leucocratic segregate (J809-15) of the areas studied in this work show a large morphological variety suggesting a complex growth history (Fig. 4). A large amount of inherited crystals and crystal cores has been found (Table 3), and they are interpreted as xenocrysts because of the crystallization ages and because their zoning is truncated by crystal limits or the overgrowths, respectively. Most of them present uneven overgrowths that yield ages known for major tectono-thermal processes previously described in the Spanish Central System batholith. However, geochronological results also reveal the presence of abundant Cambro-Ordovician ages in the analyzed samples, which had not been described to date in the central part of the Gredos massif.

5.2.1 Sample J809-13. Qtz-dioritic enclaves

Only a few crystals were obtained from Qtz-dioritic enclaves. These grains form a heterogeneous population, variably in size (small- to medium-grained crystals), in morphology (sub-euhedral to sub-rounded, needle-shaped to stubby and equant prisms) and in CL-response (simple acicular zircon with longitudinal zoning, simple concentric oscillatory zoning zircons and composite grains, Fig. 4). Only one analysis, performed on a low-CL unzoned core, has yielded an inherited age of 728 ±16 Ma (Table 3). Four Ordovician ages have been found on acicular and on equant grains, ranging between 483 and 473 Ma (Fig. 5b), yielding a weighted mean age of 480 ±11 Ma (Early Ordovician, 95% conf.; MSWD = 0.18; probability = 0.91), which seems to represent the best estimate of the crystallization age of dioritic melts.

5.2.2 Sample J706-43. Nodular granites

The selected zircons from the nodular granites are complex, heterogeneous crystals, differing in size and morphology (Fig. 4). They show a strong morphological and textural variety. This sample includes acicular simple zircon crystals (e.g., grains 8, 19 and 21 in Figure 4) and subhedral composite grains with inherited cores (e.g., grains 3, 15 and 22; Fig. 4).

The youngest ages are Carboniferous, ranging between 350 and 305 Ma. In addition, the results comprise several groups of inherited ages (lower-middle Proterozoic, Cryogenian-Ediacaran and Cambrian-Ordovician ages). Cambro-Ordovician ages were obtained on a single non-composite acicular grain with oscillatory zoning (21 in Figure 4), with a Th/U ratio of 0.55, on a low-CL unzoned external narrow rim surrounding a polyphase grain (1 in Figure 4), and on a weak concentric zoned intermediate zircon stage (grains 4 and 5 in Figure 4), the last three analyses showing an uniform and a relatively low Th/U ratio (average 0.07). Leaving aside analysis 21 of the single oscillatory zoned crystal, the remaining three analyses are equal within analytical uncertainty (MSWD = 0.21; probability = 0.81), yielding a weighted mean $^{206}Pb/^{238}U$ age of 484.4 ±5.7 Ma (95% conf). This mean age corresponds to the Cambrian-Ordovician transition, and match those obtained on zircons from the Qtz-dioritic enclaves (described above).

Most Carboniferous ages are found in low-CL, unzoned to tenuous concentric zoned overgrowths with very low Th/U ratios (e.g., 9, 18, 22, 25 - Table 3 and Figure 4), consistent with new zircon addition during high-grade metamorphic events (Williams & Claesson 1987; Williams, 1998, Heaman et al. 1990, Wang et al., 2011), spanning a wide range of ages from ca. 350-305 Ma. Also, a needle-shaped non-composite grain with a distinct parallel banded zoning (grain 8, Fig. 4) and a moderate Th/U ratio = 0.8, gave a $^{206}Pb/^{238}U$ age of ca. 323 Ma. The seven Carboniferous ages were concordant within analytical uncertainty, but there was a very large range in their radiogenic 204-corrected $^{206}Pb/^{238}U$ apparent ages. Analysis 11.2 (Table 3) probably overlaps the old detrital host grain, thus giving a Devonian (ca. 397 Ma) apparent age. Two analysis (3.2, 18.1 in Table 3), obtained from overgrowing pyramidal crystal faces, yield 341 and 350 Ma, respectively, and they are equivalent to the oldest ages of migmatization in the Spanish Central System batholith (Peña Negra) (Montero et al., 2004). The remaining $^{206}Pb/^{238}U$ ages span from an upper value of ca. 323 Ma obtained from a layered acicular zircon (grain 8) to a lower end represented by four very low Th/U thin external rims (9, 22, 24 and 25; Table 3) that yielded a late Carboniferous weighted mean $^{206}Pb/^{238}U$ age of 310.6 ±7.4 Ma (95% conf.).

Figure 5a shows the concordia diagram for the nodular granite sample. A detailed section of the diagram (Fig. 5b) highlights the inherited Cambro-Ordovician ages of the nodular granites, together with those of the Qtz-dioritic enclaves and Crd-leucogranites. All Cambro-Ordovician and Carboniferous ages are concordant, suggesting that the youngest ages are not the result of partial radiogenic Pb loss from a primary Ordovician isotopic composition. Rather, the youngest age cluster, together with the Th/U composition in the range 0.01-0.1, represents an independent stage of zircon precipitation during metamorphism or partial melting of a peraluminous rock (Williams & Claesson 1987; Heaman et al. 1990; Williams 2001).

5.2.3 Sample J809-15. Crd-Leucogranites

Leucocratic segregates included in the high-grade complex contain very scarce zircon crystals (low Zr concentration in the whole rock; Table 2). Only 8 zircon crystals were found and CL imaging revealed both composite and simple grains. CL images also show a variable width dark-CL rim surrounding a low or high-CL weakly concentric zoned core in some grains (grains 1, 3 and 4; Fig. 4 and Table 3). Grain 2 is a simple sub-rounded dark-CL unzoned zircon with an excess of Th (very high Th/U ratio), yielding a $^{206}Pb/^{238}U$ age of 280 ±6.8 Ma, equal within analytical uncertainty to analysis 4.1 (287 ±7.4 Ma), obtained from dark-CL unzoned external rim surrounding an internal area through an transgressive interface with evidences of marginal resorption.

Only two analyzed cores yield reliable inherited ages of 512 and 739 Ma. In addition, the younger (Carboniferous) ages (Table 3) match those found in granitoids affected by late U-Th-Pb re-equilibration probably under sub-solidus conditions (Díaz-Alvarado et al., 2013).

6.- Discussion

6.1 Geochemical constraints.

Geochemical features of nodular granites from the Gredos massif match the geochemical signatures of the Cambro-Ordovician ferrosilicic magmatism represented by the Ollo de Sapo Formation and the metavolcanic rocks of the North SGC Domain (Fig. 3). Silica-rich and moderately peraluminous nodular granites (Fig. 3b) show large FeO and MgO contents relative to low CaO values (Fig. 3a, c, d, Table 2). In addition, some of the most prominent textural characteristics in the nodular granites, specifically the presence of K-feldspar nodular megacrysts (Fig. 2d), resemble to those described in the Cambro-Ordovician metavolcanic rocks, in spite of the protracted process of deformation and metamorphism registered in the Gredos massif during the Variscan orogeny (Carboniferous). Moreover, high-grade complexes contain large amounts of enclaves of Qtz-dioritic to tonalitic composition with calc-alkaline affinity (Fig. 3) and Cambro-Ordovician ages (Fig. 4, 5).

Nebulitic migmatites that make up the high-grade metamorphic complexes along with nodular granites show intermediate geochemical features between the SGC Neoproterozoic metasedimentary rocks (found in nebulitic domains as migmatitic enclaves with flebitic textures) and the ferrosilicic rocks (Fig. 3). This is consistent with the complex textural features found in these rocks, where metasedimentary enclaves, K-feldspar nodules and Bt-Crd-Sil restites show chaotic relationships. This suggests that these nebulitic domains are comprised by SGC metasedimentary rocks and ferrosilicic affinity rocks merged together during Variscan tectonic mixing and high-grade metamorphic processes. Leucogranitic dykes and blobs found in nebulites show magma-magma contacts with the nebulite matrix and follow previous rheological weaknesses such as the granite-nebulite boundary. These are high-silica, low CaO and MgO anatectic Crd-leucogranites (Fig. 3d), albeit high FeO contents point to a FeO-rich source like the ferrosilicic rocks. However, according to their Permian zircon ages, the segregation of Crd-leucogranites in the nebulite matrix is probably post-Variscan and not related to the Cambro-Ordovician origin of the ferrosilic igneous protolith.

6.2 The meaning of Cambro-Ordovician and older ages

Cambro-Ordovician ages were found in zircons obtained from Qtz-dioritic enclaves and nodular granites located in a high-grade metamorphic complex of the Gredos massif. The Qtz-dioritic enclaves are present as dismembered dyke-like domains (Fig. 1c), forming several blobs of multiple sizes that show complex relations with the host migmatites (both sharp and magma-magma contacts are present in a single enclave, Fig. 2f). The weighted mean $^{206}Pb/^{238}U$ age of 480 ±11 Ma obtained for these intermediate igneous enclaves can be considered equal within analytical uncertainty to the igneous crystallization age obtained for Bercimuelle metagranite located at Northern Gredos (Talavera et al., 2013), as well as similar to those ages obtained from the Urra Formation volcaniclastic rocks ranging from 494.6 ±6.8 Ma to 488.3 ±5.2 Ma (Solá et al., 2008) and localized near the Central Iberian–Ossa-Morena transition zone (SW Iberian Massif) (Fig. 5c, Table 1).

Regarding the highly deformed and metamorphosed nebulites and nodular granites, their zircon grains show a strong morphological and textural variety. Textural, morphological, chronological and petrological evidences led to distinguish among zircons crystallized from anatectic melts, zircons removed from paleosomes and zircons from paleosomes overgrown in the anatectic melts (see also Díaz-Alvarado et al., 2011, 2013). The nebulites and nodular granites also provided Cambro-Ordovician ages between 490 and 460 Ma (nodular granite sample, J706-43; Table 3, Fig. 4, 5). These ages are yielded mostly by zircon overgrowths with uniform and relatively low Th/U ratio (average 0.07), although a simple elongated crystal with a Late Ordovician age is present too. These data can be an indication of zircon precipitation from a felsic peraluminous melt (Williams and Claesson 1987; Heaman et al. 1990). Three analyses performed on zircon overgrowths yielded a weighted mean $^{206}Pb/^{238}U$ age of 484.4 ±5.7 (95% conf.), which is essentially equal, within analytical uncertainty, to the age of the Qtz-dioritic enclaves. Therefore, the Cambro-Ordovician ages found in the Qtz-diorite enclaves may indicate that the emplacement of these typical calc-alkaline intrusive rocks approximately coincides with the generation, emplacement and extrusion of ferrosilicic magmatism (Fig. 5).

However, Cambro-Ordovician ages represent only 12.5% of the U-Th-Pb ages obtained (32 total analyses, Table 3), due to the large number of cores and inherited zircons found in the nodular granite sample. This is consistent with geochronological studies carried out in the Ollo de Sapo formation and other Cambro-Ordovician metavolcanic rocks and gneisses in the Iberian Massif (Montero et al, 2007; Talavera, 2009; Talavera et al., 2013). The high percentage of zircon inheritance observed in nodular granites matches the significant component of inheritance reported on Cambro-Ordovician metagranites and metavolcanic rocks of central and NW Iberia composed of Ediacaran–Early Cambrian (65%) and, to a lesser extent, Cryogenian, Tonian, Mesoproterozoic, Orosirian and Archean pre-magmatic cores (Fig. 6) (Montero et al, 2007; Talavera, 2009; Talavera et al., 2013). The Ollo de Sapo and Urra Formations show a simple Ediacaran population (600-610 Ma), whereas the NW Iberian and Central Iberian orthogneisses exhibit three populations at 540-550, 575-585 and 605-615 Ma (Talavera et al., 2013). The studied nodular granites yielded two Ediacaran populations at ca. 570 and 620 Ma (Fig. 6a). Moreover, they show an outstanding frequency of young Cryogenian ages (640-660 Ma), as well as the absence of Mesoproterozoic (Stenian) zircons. These features make them slightly different from those observed in other Cambro-Ordovician igneous rocks of the Iberian Massif. A compilation of U-Pb ages from inherited zircon grains analyzed on Cambro-Ordovician metagranites and metavolcanic rocks from other sections of the Western European Variscan Belt performed by Talavera et al. (2013) shows three distinctive Ediacaran-Early Cambrian populations whose statistical age ranges match those of the Iberian Cambro-Ordovician rocks, including those obtained in this work. Therefore, despite local heterogeneities, the source that has undergone partial melting to give this Cambro-Ordovician magmatism is essentially Pan-African (e.g. Talavera et al., 2013) and/or Cadomian (Pereira, 2014).

Although the number of analysis providing pre-Ordovician ages (inherited cores and zircons) does not allow us to be conclusive and the geochronological data must be taken cautiously, the comparison of these results with those obtained in the main igneous and sedimentary units ascribed to the Ordovician period could shed light on the complex origin of nodular granites and associated nebulites from the Gredos massif (Fig. 6b, c). In this sense, the high frequency of early Ediacaran-late Cryogenian ages (620-660 Ma) in nodular granites is characteristic of Central Iberian gneisses in contrast to NW Iberian gneisses (Fig. 6c). These ages and the marginal representativity of Mesoproterozoic (Stenian) zircons bear striking similarities with the late Ediacaran SGC (Beiras Group) and with the Early Ordovician arkosic quartzite of the Sarnelhas Formation from the southwest Central Iberian Zone (Pereira et al., 2012) (Fig. 6b). In particular, the affinities with Sarnelhas arkosic quartzite are remarkable because this unit is characterized by a significant population of Ediacaran-Cryogenian detrital zircons and only a few Tonian and Mesoproterozoic ages (percentages <1%).

6.3 The meaning of late Paleozoic ages.

The youngest zircon ages (7 analyses) yielded by the nodular granite sample (J706-43; Table 3) point to a protracted metamorphic record during Carboniferous times, in addition to a Cambro-Ordovician magmatic event. These ages were found by analyzing thin overgrowths over rounded inherited zircons of different ages, except for grain 8 (Fig. 4). Furthermore, these analyses mostly have Th/U ratio less than 0.01, which is usually related to metamorphic processes (Wang et al., 2011). The Carboniferous ages found in these overgrowths can be grouped in two main events: 1) two ages of 350-340 Ma account for the older Variscan migmatization events (Montero et al., 2004), and 2) five ages (323-305 Ma) are contemporary to the intrusive phase during the batholith building (Díaz-Alvarado et al., 2013). This wide range of ages reflects that the high-grade (essentially high-temperature) conditions were maintained during a continuous emplacement and amalgamation of a number of intrusive granitoid layers that comprise the batholith (Díaz-Alvarado et al., 2013).

Early Permian ages found in the leucogranitic segregates (J809-15; Table 3) included in the nebulites have been described in the intrusive granitoids (Díaz-Alvarado et al., 2013) and, though secondary processes are not discarded (Pb loss or deformation along sub-solid shear zones may affect the isotopic ratios), they point out that the complex texture, internal structure and lithological variety of nebulites are due to the superposition of high-grade metamorphic and anatectic processes that may reach the Permian. Nevertheless, concordant data would not exclude the possibility that only the younger group represents a real igneous-metamorphic event, and that isotopic disequilibrium has left a trail of meaningless ages (Bea and Montero, 2013).

6.4 Tectonic setting.

The extensive Cambro-Ordovician ferrosilicic intrusive granitoids and their sub-volcanic and extrusive counterparts evidence the close relationship between ferrosilicic and calc-alkaline magmatism during the Cambro-Ordovician magmatic event found in the Central Iberian Zone and the Galicia-Trás-os-Montes Zone: (i) Ollo de Sapo Domain near the contact between the Central Iberian and West-Asturian Leonese zones; (ii) Northern SGC Domain defined by the lineament of the Central Iberian and NW Iberian orthogneisses; iii) Beira Baixa-Central Extremadura tonalite-granodiorite belt that extends from Gouveia (Portugal) to Zarza (Spain); iv) Portalegre-Urra domain at the Central Iberian–Ossa-Morena transition zone (SW Iberian Massif) (Table 1). Indeed, recently, it has been proposed the presence of a Cambro-Ordovician magmatic arc in the Central-Iberian Zone (the Beira Baixa-Central Extremadura belt) (Rubio-Ordóñez et al., 2012; Díez Fernández et al., 2015). Qtz-dioritic enclaves found in the Gredos massif (Prado de las Pozas), which plot into the calc-alkaline series of cordilleran magmatism, may represent evidence of the existence of such Cambro-Ordovician magmatic arc.

Figure 7 shows a schematic section of the northern Gondwana margin during Cambro-Ordovician times based on previous works (Fernández et al., 2008; Rubio Ordóñez et al., 2012; Villaseca et al., 2014) and new geochemical and geochronological data from high-grade complexes of the Gredos massif. The coincidence of subduction processes and an extensional setting in the back-arc region promoted the concurrency of calc-alkaline magmatism, typical of active continental margins, and the generation of peraluminous ferrosilicic magmas related to the emplacement of sedimentary material (cold diapirs) in the lithosphere mantle. This Cambro-Ordovician magmatic event has been described in the realm of a back-arc rifting that affected the active continental margin of North-Gondwana during the inception of the Rheic Ocean (e.g., van Staal et al., 1998; Stampfli and Borel, 2002; Fuenlabrada et al., 2010; Díez Fernández et al., 2012b). The extensional tectonic setting within the active continental margin is favorable for the generation of cold diapirs, mainly formed by sedimentary material introduced into the subduction channel (Fernández et al., 2008; Castro et al., 2009). This extensional setting allows the emplacement (relamination in the sense of Hacker et al., 2011) of these cold diapirs at the top of the mantle wedge and facilitates their fast rise throughout the crust. The high pressures and temperatures estimated to generate the ferrosilicic magmatism and the large concentration of inherited ages point to a process of high-percentage melting in the crust-mantle boundary and a rapid ascent to shallow depths in the crust to generate ferrosilicic magmatism. Silicic compositions (“cold granites”, in the sense of Miller et al., 2003), and the brief time for zirconium dissolution processes could explain these anomalous abundances in inherited zircons. The presence of typical calc-alkaline cordilleran granitoids contemporary with ferrosililicic volcanism supports a subduction-related origin for the Cambro-Ordovician magmatism asserted on the generation of hybrid-andesitic plumes.

7.- Conclusions

Nodular granites and nebulites from the Gredos massif constitute an important domain in the high-grade metamorphic complexes present as part of the middle crust that host late Paleozoic granitoids in the Spanish Central System batholith. These rocks are closely related to Neoproterozoic metasedimentary rocks that constitute the SGC, and have been highly deformed and metamorphosed (nebulitic textures depict a large partial melting percentage) in the course of the Variscan orogeny.

Geochemically, nodular granites are rich in silica, moderately peraluminous and rich in FeO and MgO relative to the low CaO. These geochemical features clearly relate these rocks to crustal sources that include the ferrosilicic Cambro-Ordovician magmatism of the Ollo de Sapo, north of SGC and Urra-Portalegre domains. Qtz-diorite enclaves are present within these high-grade complexes (nebulitic migmatites, nodular granites and Crd-leucogranites). They show calc-alkaline geochemical signatures and complex textural relations with the host migmatites. Cambro-Ordovician ages (between 490 and 460 Ma) found in nodular granites and Qtz-diorite enclaves of the Gredos massif confirm that these high-grade complexes are in part derived from igneous-sedimentary complexes related to the extensive Cambro-Ordovician magmatic event that affected the North-Gondwana margin.

The narrow spatial and temporal link between the peraluminous ferrosilicic and the cordilleran calc-alkaline magmatism points to the evolution of a magmatic arc associated with the subduction of the Iapetus or Tornquist Ocean, and to the activity of an arc-back-arc tectonic setting during the the inception of the Rheic Ocean. The details of this process are not fully understood, although the presence and interaction of contemporary ferrosilic and calc-alkaline magmatic rocks in the central part of the Gredos massif should be taken into account and adequately explained in future models of the Cambro-Ordovician evolution of the North-Gondwana margin.

Although ferrosilic and calc-alkaline magmatism have been located in very specific and separated tectonic settings on the structural configuration of the Cambro-Ordovician northern margin of Gondwana, the coalescence of intrusive Qtz-diorites and ferrosilicic nodular granites in intermediate areas points to similar petrogenetic conditions for this magmatic association, as has already been proved by experimental petrology. The generation of hybrid-andesitic plumes and cold diapirs of sedimentary material, and their relamination in the crust-mantle boundary is a feasible explanation for the extensive magmatism that accompanies the opening of the Rheic Ocean during the Cambro-Ordocian evolution of the North-Gondwana margin.

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Figure captions

Figure 1. (a) Geological sketch of the Iberian Massif indicating in black color the main occurrences of Cambro-Ordovician igneous rocks. The black box indicates the location of the studied area. Abbreviations: CZ: Cantabrian Zone, WALZ: Western Asturian-Leonese Zone, GTMZ: Galicia-Trás-os-Montes Zone, CIZ: Central Iberian Zone, OMZ: Ossa-Morena Zone, SPZ: South-Portuguese Zone. SGC: Schist and Greywacke Complex. (b) Geological map of the central area of the Spanish Central System batholith (see location in Fig. 1a) indicating the location of the Gredos massif and the studied area. (c) Detailed geological map of Prado de las Pozas in central Gredos (see location in Fig. 1b).

Figure 2. (a) Crd-Leucogranite layer in Prado de las Pozas. Its most outstanding feature is the presence of Crd nodules (some Bt can also be seen) oriented parallel to the main foliation in the leucogranite layer. (b) Medium- to fine-grained nebulites with a huge number of Bt-Crd-Sil restites. (c) Large-size Bt-Crd-Sil restite. (d) Large Kfs nodules (6-10 cm in diameter) in nodular granites and nebulites. (e) Roof contact between nodular granites (to the right) and the intrusive granitoids (to the left) in Prado de las Pozas (Las Pozas layer, Díaz-Alvarado et al., 2011). The contact, 4-6 m wide, consists of several interbedded sheets of Crd-monzogranites (including Kfs megacrysts and mafic microgranular enclaves) and nodular granites (including Crd and Kfs nodules, and leucogranite bands). (f) Qtz-diorite enclaves in nebulites. They show lobulate contacts and variably sized fragments. Qtz-diorite enclaves showing lenticular or ellipsoidal shapes also occur in Crd-leucogranite layers.

Figure 3. Geochemical features of Prado de las Pozas samples (central Gredos massif). For comparison, main units representing the Cambro-Ordovician magmatism and the Neoproterozoic metasedimentary rocks of the Iberian Massif are included. a) FeOt/FeOt+CaO vs SiO_2. b) ASI (Alumina Saturation Index) vs SiO_2. c) A–B diagram by Debon and Le Fort (1983, 1988). d) CaO

vs MgO diagram showing the trends drawn by calc-alkaline magmatic associations (LLD: Liquid Lines of Descent) (Castro, 2013b), and leucogranites. e) F–An–Or plot (Castro, 2013b) including the geochemical cotectic evolution of cordilleran granitoids and leucogranites. Greywackes and pelites fields are marked for comparison with Gredos massif samples. 1- Central Gredos samples (Díaz-Alvarado et al., 2011). 2- Average Ollo de Sapo (Iberia). Compilation from Fernández et al. (2008). 3- Hiendelaencina and Villadepera metavolcanic rocks and Antoñita and Miranda do Douro gneisses from Montero et al. (2007). 4- Urra Formation volcaniclastic rocks (Solá et al., 2008). 5- Outlined fields for Ollo de Sapo and Neoproterozoic sediments (SGC) in Iberia are obtained from García de Figuerola (1966), Capdevila (1969), Gil Ibarguchi (1978), Navidad (1978), Holtz (1987), Beetsma (1995), Briggs (1995), Ugidos et al. (1997a,b, 2001), Valladares et al. (2000), Castro et al. (2000, 2003), Corretgé et al. (2001), Bea et al. (2003).

Figure 4. Cathodoluminescence images of some of the zircons from the three samples selected for the SHRIMP U–Th–Pb analysis. Spots location and ^{206}Pb/^{238}U ages are indicated. Data are given in Table 3. Scale bars (white lines) are 100 μm.

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Figure 7. Schematic cross-section (not to scale) depicting a tectonic model for the origin of the Cambro-Ordovician magmatism of the Central Iberian Zone (Iberian Massif). Cold diapirs rooted in the subduction mélange (e.g. Gerya and Yuen, 2003, Castro and Gerya, 2008) ascended through the mantle wedge and accumulated at the basal part of the lithosphere, giving place to partially molten resevoirs of mafic or intermediate to felsic magmas (e.g. Castro and Gerya, 2008, Castro et al., 2010, Hacker et al., 2011) and feeding the magmatic arc and the extensional back-arc region. Cold diapirs made by molten sediments predominated at the back-arc region. The arc-back-arc setting shown in the section is inspired in similar interpretative sketches for this Cambro-Ordovician event published by Fernández et al. (2008), Rubio Ordóñez et al. (2012) and Villaseca et al. (2014).

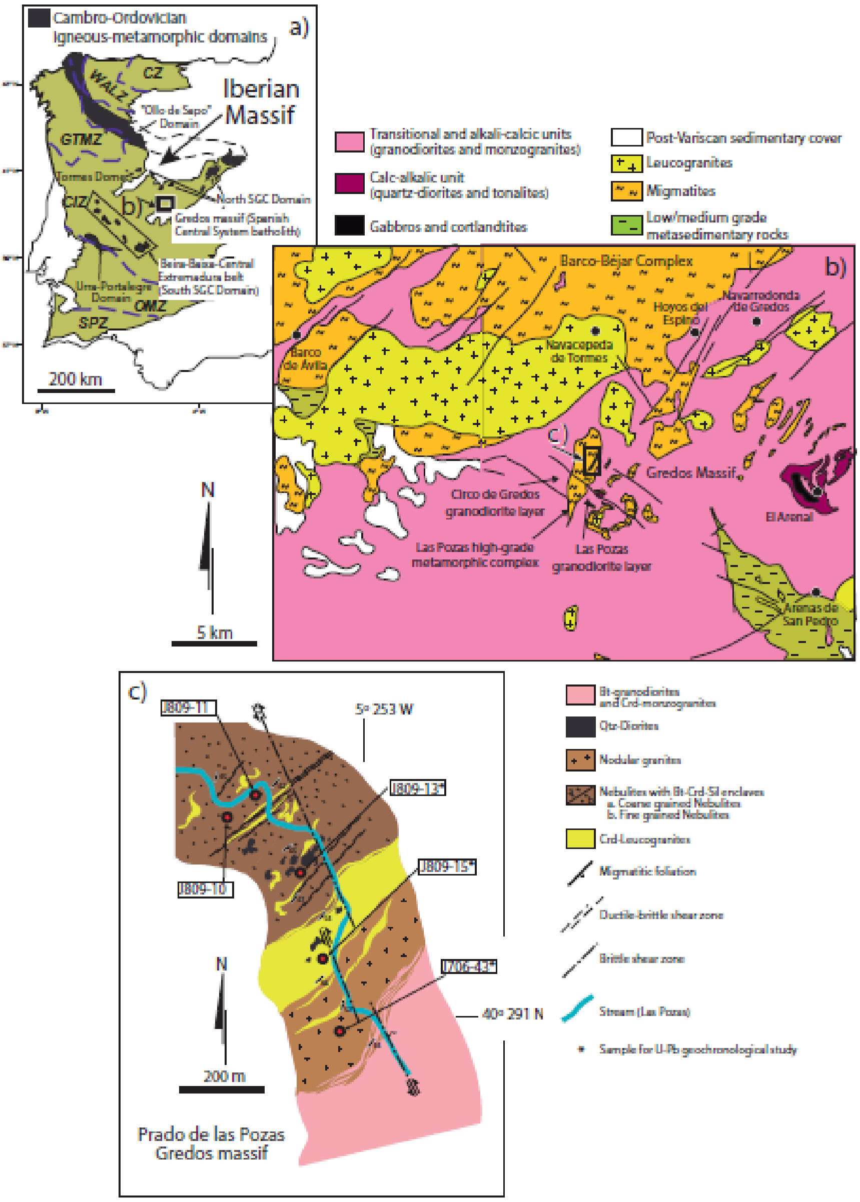


Figure 1. (a) Geological sketch of the Iberian Massif indicating in black color the main occurrences of Cambro-Ordovician igneous rocks. The black box indicates the location of the studied area. Abbreviations: CZ: Cantabrian Zone, WALZ: Western Asturian-Leonese Zone, GTMZ: Galicia-Trás-os-Montes Zone, CIZ: Central Iberian Zone, OMZ: Ossa-Morena Zone, SPZ: South-Portuguese Zone. SGC: Schist and Greywacke Complex. (b) Geological map of the central area of the Spanish Central System batholith (see location in Fig. 1a) indicating the location of the Gredos massif and the studied area. (c) Detailed geological map of Prado de las Pozas in central Gredos (see location in Fig. 1b).

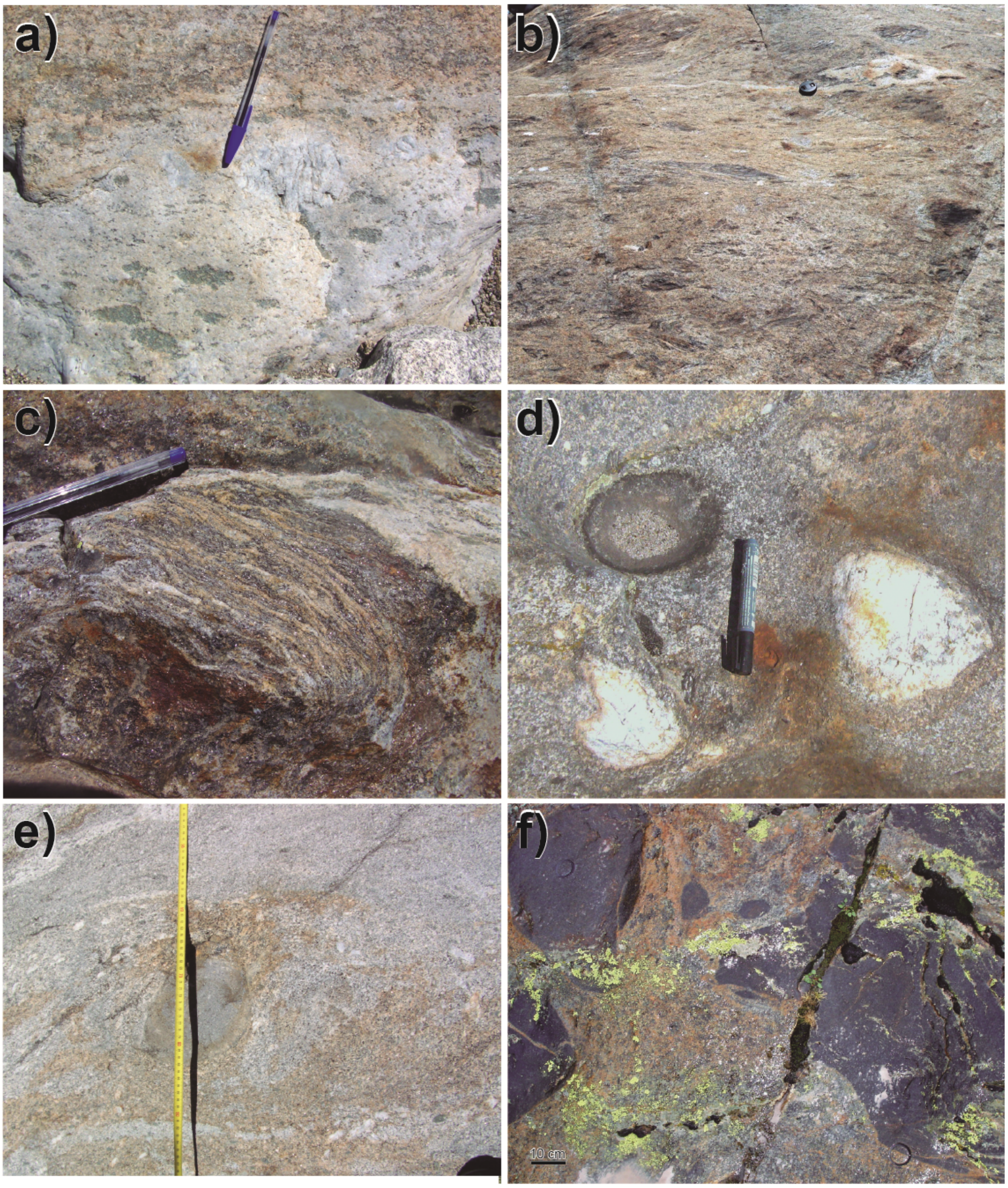


Figure 2. (a) Crd-Leucogranite layer in Prado de las Pozas. Its most outstanding feature is the presence of Crd nodules (some Bt can also be seen) oriented parallel to the main foliation in the leucogranite layer. (b) Medium- to fine-grained nebulites with a huge number of Bt-Crd-Sil restites. (c) Large-size Bt-Crd-Sil restite. (d) Large Kfs nodules (6-10 cm in diameter) in nodular granites and nebulites. (e) Roof contact between nodular granites (to the right) and the intrusive granitoids (to the left) in Prado de las Pozas (Las Pozas layer, Díaz-Alvarado et al., 2011). The contact, 4-6 m wide, consists of several interbedded sheets of Crd-monzogranites (including Kfs megacrysts and mafic microgranular enclaves) and nodular granites (including Crd and Kfs nodules, and leucogranite bands). (f) Qtz-diorite enclaves in nebulites. They show lobulate contacts and variably sized fragments. Qtz-diorite enclaves showing lenticular or ellipsoidal shapes also occur in Crd-leucogranite layers.

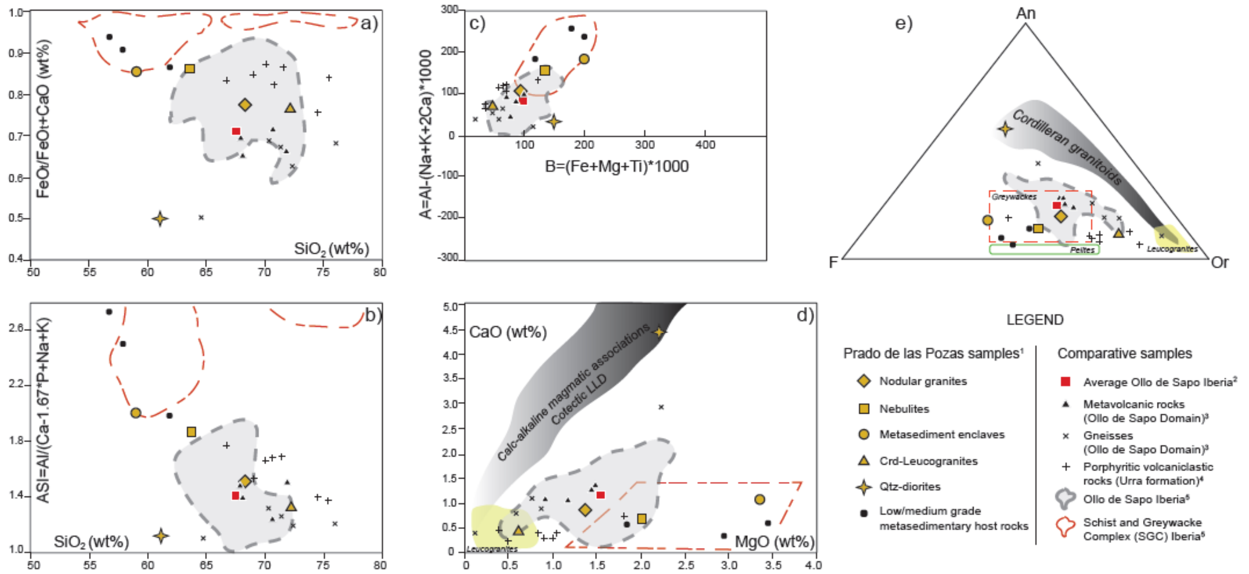
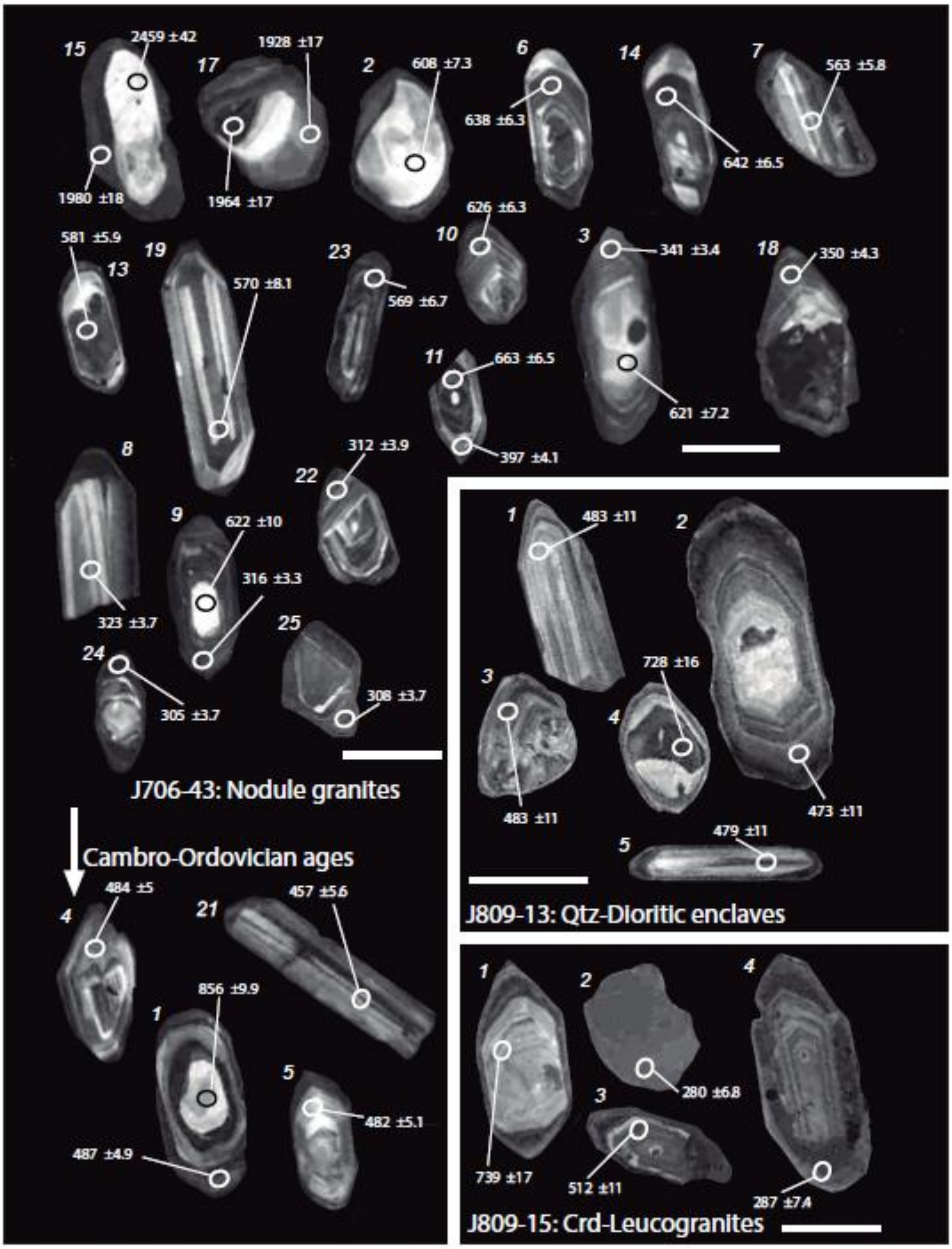


Figure 3. Geochemical features of Prado de las Pozas samples (central Gredos massif). For comparison, main units representing the Cambro-Ordovician magmatism and the Neoproterozoic metasedimentary rocks of the Iberian Massif are included. a) FeOt/FeOt+CaO vs SiO2. b) ASI (Alumina Saturation Index) vs SiO2. c) A–B diagram by Debon and Le Fort (1983, 1988). d) CaO vs MgO diagram showing the trends drawn by calc-alkaline magmatic associations (LLD: Liquid Lines of Descent) (Castro, 2013b), and leucogranites. e) F–An–Or plot (Castro, 2013b) including the geochemical cotectic evolution of cordilleran granitoids and leucogranites. Greywackes and pelites fields are marked for comparison with Gredos massif samples. 1- Central Gredos samples (Díaz-Alvarado et al., 2011). 2- Average Ollo de Sapo (Iberia). Compilation from Fernández et al. (2008). 3- Hiendelaencina and Villadepera metavolcanic rocks and Antoñita and Miranda do Douro gneisses from Montero et al. (2007). 4- Urra Formation volcaniclastic rocks (Solá et al., 2008). 5- Outlined fields for Ollo de Sapo and Neoproterozoic sediments (SGC) in Iberia are obtained from García de Figuerola (1966), Capdevila (1969), Gil Ibarguchi (1978), Navidad (1978), Holtz (1987), Beetsma (1995), Briggs (1995), Ugidos et al. (1997a,b, 2001), Valladares et al. (2000), Castro et al. (2000, 2003), Corretgé et al. (2001), Bea et al. (2003).



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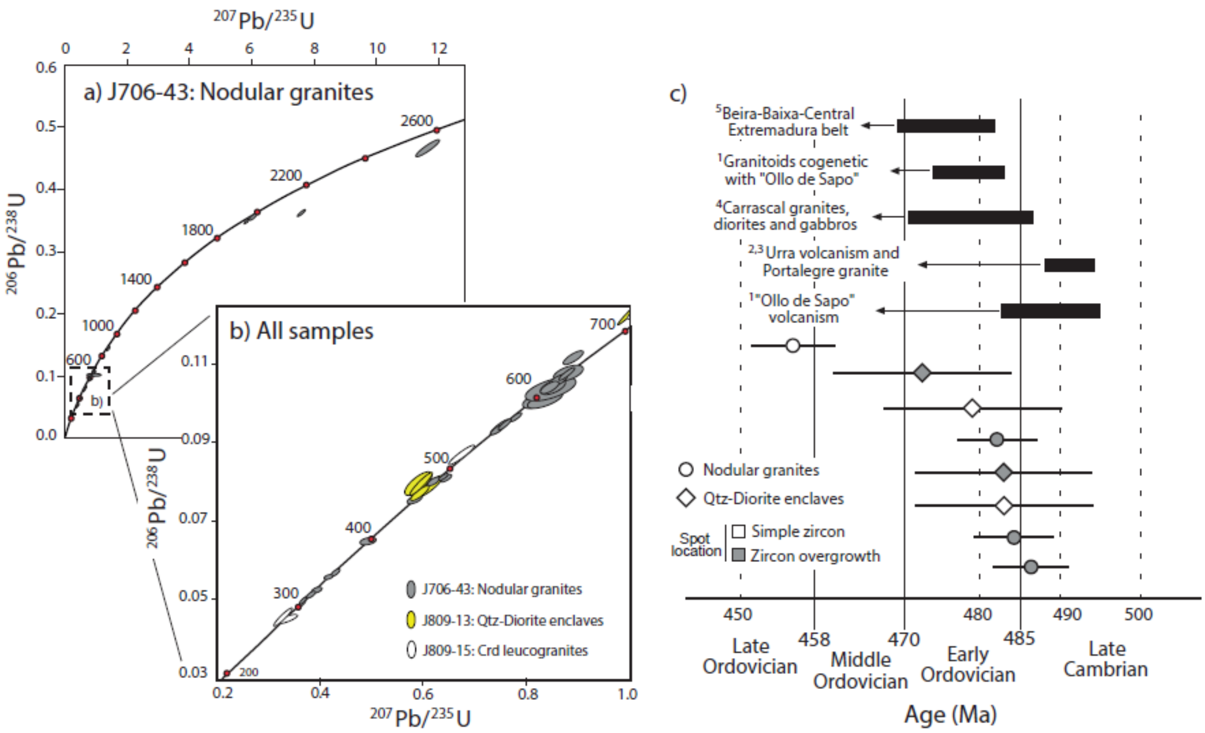

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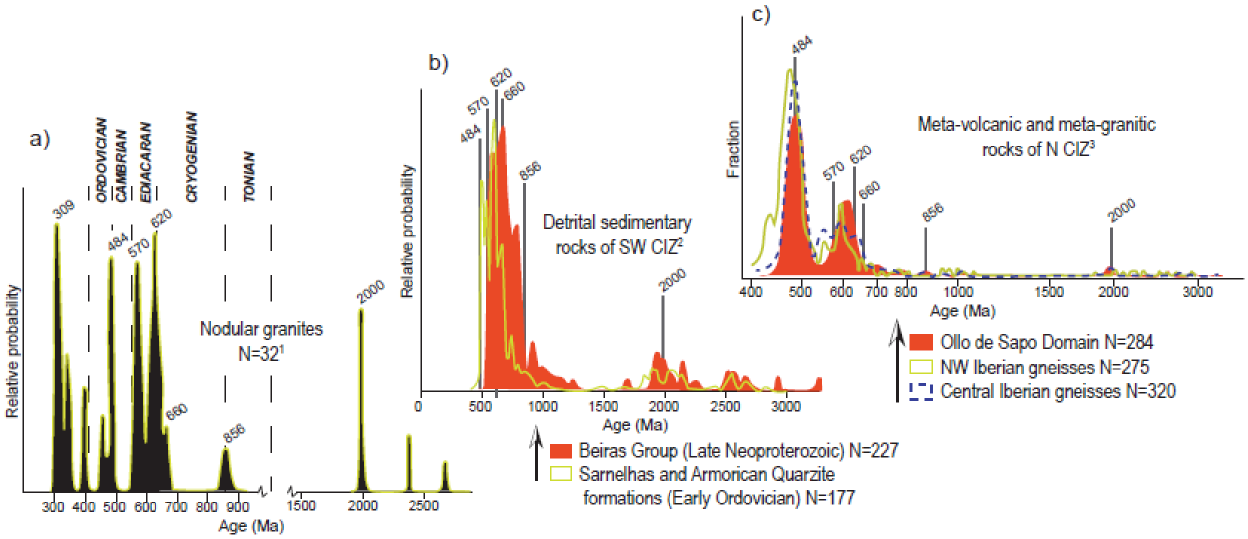

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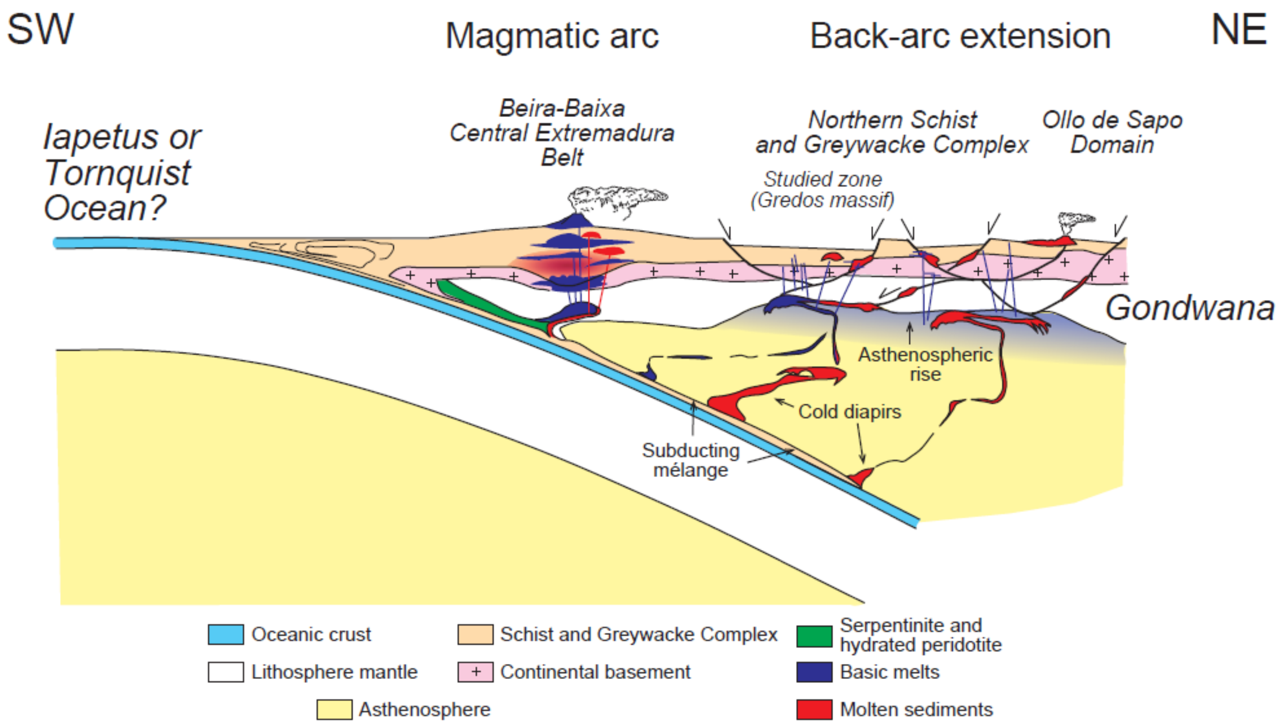

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Table 1

Rock type	Geological location	Crystallization age (Ma)	Analytical method	Reference
Metavolcanic rocks (Ollo de Sapo)	Villadepera (Ollo de Sapo Domain, NW Iberia)	483 ±4	Zrn U-Pb ion microprobe and LA-ICPMS and Pb-Pb TIMS	Montero et al. (2007)
Metavolcanic rocks (Ollo de Sapo)	Hiendelaencina (Ollo de Sapo Domain, central Iberia)	495 ±5 - 483 ±3	Zrn U-Pb ion microprobe and LA-ICPMS and Pb-Pb TIMS	Montero et al. (2007)
Metavolcanic rocks and Metagranites (Ollo de Sapo)	Sanabria, Trives and Vivero (NW Ollo de Sapo Domain)	492 ±4 - 486 ±5	Zrn U-Th–Pb ion microprobe and LA-ICPMS	Montero et al. (2009)
Metagranite (miranda do Douro)	Villadepera (Ollo de Sapo Domain, NW Iberia)	483 ±3	Zrn U-Pb ion microprobe and LA-ICPMS	Bea et al. (2006)
Metagranite (Antoñita)	Hiendelaencina (Ollo de Sapo Domain, central Iberia)	474 ±4	Zrn U-Pb ion microprobe and LA-ICPMS and Pb-Pb TIMS	Montero et al. (2007)
San Sebastian metagranite (Ollo de Sapo)	Sanabria (NW Ollo de Sapo Domain)	470 ±3	Zrn U-Th–Pb ion microprobe and LA-ICPMS	Montero et al. (2009)
Ignimbrite	Sanabria (NW Ollo de Sapo Domain)	488 ±6	Zrn U-Pb TIMS	Díez-Montes et al. (2010)
Augen gneiss	Sanabria (NW Ollo de Sapo Domain)	472 ±14	Zrn U-Pb TIMS	Díez-Montes et al. (2010)
Metagranites ("Galician" gneisses)	Several locations (Galicia Trás-os-Montes Zone)	497 ±6 - 462 ±8	Zrn U-Th–Pb ion microprobe and LA-ICPMS	Talavera et al. (2013)
Granodiorite orthogneiss	Malpica-Tui Complex (Galicia Trás-os-Montes Zone)	489 ±4	Zrn U–Th–Pb SHRIMP-RG	Díez Fernández et al. (2012b)
Alkali-granite orthogneiss	Malpica-Tui Complex (Galicia Trás-os-Montes Zone)	474 ±3	Zrn U–Th–Pb SHRIMP-RG	Díez Fernández et al. (2012b)
Alkaline and peralkaline granite gneiss	Malpica-Tui Complex (Galicia Trás-os-Montes Zone)	475-470	Zrn U–Th–Pb SHRIMP-RG	Díez Fernández et al. (2012b)
Metavolcaniclastic rocks (rhyolites and dacites)	Bragança–Alcañices area (Galicia Trás-os-Montes Zone)	500 ±4 - 489 ±4	Zrn U–Th–Pb SHRIMP	Farias et al. (2014)
Alkaline metarhyolite	Queiroga Series (Galicia Trás-os-Montes Zone)	475 ±2	Zrn U-Pb LA-MC-ICPMS	Valverde-Vaquero et al. (2005)
Calc-alkaline rhyolites	Eastern Galicia-Trás-os-Montes Zone	455	Zrn U-Pb LA-MC-ICPMS	Dias da Silva et al. (2015)
K-bentonites (Super-eruption?)	Several locations (NW Iberia, Cantabrian Zone)	477 ±1	Zrn and Mnz U–Pb ID-TIMS	Gutiérrez-Alonso et al. (2016)
Metagranites ("Castilian" gneisses)	Several locations (Central Iberian Zone)	498 ±4 - 471 ±7	Zrn U-Th–Pb ion microprobe and LA-ICPMS	Talavera et al. (2013)
Intraplate basalt	Central Iberian Zone	455	Zrn U-Pb LA-MC-ICPMS	Dias da Silva et al. (2015)
Meta-tholeiites	Tenzuela (Central Iberian Zone)	473 ±2	Zrn U–Th–Pb SHRIMP	Villaseca et al. (2015)
Anatectic rocks	Sotosalvos (Central Iberian Zone)	480 - 464 ±3 (Pre-Hercynian ages)	Zrn U–Th–Pb SHRIMP-RG	Castiñeiras et al. (2008)
Tonalites and granodiorites (Beira Baixa–Central Extremadura tonalite belt)	Zarza la Mayor (SW Central Iberian Zone)	478 ±1	Zrn U–Pb LA-ICPMS and ID-TIMS	Rubio-Ordóñez et al. (2012)
Tonalites and granodiorites (Beira Baixa–Central Extremadura tonalite belt)	Arroyo de la Luz and Zarza de Montánchez (SW Central Iberian Zone)	470 ±15 and 482 ±10	Mnz EMPA	Rubio-Ordóñez et al. (2012)
Tonalite/granodiorite and Bt+Ms granites (Beira Baixa–Central Extremadura tonalite belt)	Oledo (SW Central Iberian Zone)	481 ±1 - 478 ±1	Zrn and Mnz U–Pb ID-TIMS	Antunes et al. (2009)
Porphyritic felsic volcanoclastic rocks (Urra Formation)	Urra (Central Iberian/Ossa-Morena transition zone)	495 ±7 - 488 ±5	Zrn U–Th–Pb SHRIMP	Solá et al. (2008)
Gabbros, diorites and granites (Beira Baixa–Central Extremadura tonalite belt)	Carrascal (Central Iberian/Ossa-Morena transition zone)	486 - 471	Zrn Pb-Pb TIMS	Solá et al. (2005)
Granites (Beira Baixa–Central Extremadura tonalite belt)	Portalegre (Central Iberian/Ossa-Morena transition zone)	493 ±4	Zrn U-Pb SHRIMP	Solá (2007)

Summary of geochronological data of the Cambro-Ordovician magmatism in the Iberian Massif.

Table 2: Whole rock compositions of the main facies in the high-grade metamorphic complex in Prado de las Pozas (Gredos Massif) and comparative Cambro-Ordovician igneous rocks in Iberia

Location	Prado de las Pozas (Gredos Massif)					Gredos massif			Iberia		Hiendelaencina and Villadepera				Antoñita and Miranda do Douro					Urra Formation						
Reference	Díaz-Alvarado et al. (2011)			This study		Díaz-Alvarado et al. (2011)			Fernández et al. (2008)		Montero et al. (2007)				Montero et al. (2007)					Sola et al. (2008)						
Rock type	Nodular granite	Qtz-Diorite	Nebulite	Crd-leucogranite	Metasediment enclave	Hornfels			Ollo de Sapo Average	SGC Average	Metavolcanic rock				Gneiss					Porphyritic volcaniclastic rock						
Sample	J-706-43	J809-13	J809-10	J809-15	J809-11	J-707-8	J-707-7	J709-2	(N=95)	(N=68)	CT6	CT7	GNB9	GNB8	CT4	CT10	CT11	CT9	GNB11	URRA2	URRA5	URRA8	URRA4	URRA7	URRA1	URRA3
wt %																										
SiO2	68,31	61,05	63,74	72,19	58,98	56,69	61,86	57,84	67,53	64,16	68,06	71,92	68,02	70,67	76	71,46	72,37	70,25	64,62	66,7	69,02	70,14	70,79	71,53	74,53	75,43
TiO2	0,50	1,15	0,72	0,35	1,07	0,81	0,65	0,91	0,55	0,84	0,5	0,4	0,68	0,54	0,09	0,32	0,35	0,43	0,62	0,83	0,43	0,44	0,46	0,47	0,18	0,16
Al2O3	15,51	17,64	17,23	14,68	18,92	21,03	19,21	20,45	15,79	17,64	15,76	14,81	15,34	14,44	12,88	14,45	13,92	15,07	16,07	15,91	16,12	15,63	15,27	14,99	13,6	13,12
FeOt	3,85	5,75	5,41	1,96	7,87	6,88	4,71	7,65	3,77	6,08	3,32	2,59	3,73	3,45	1,14	2,1	2,36	2,61	3,83	4,92	2,81	2,71	2,43	2,75	1,84	1,63
MgO	1,37	2,21	2,03	0,64	3,36	2,95	1,83	3,44	1,56	2,12	1,49	1,18	1,44	0,92	0,12	0,59	0,77	0,89	2,23	1,81	1,05	1	0,85	0,9	0,39	0,49
MnO	0,06	0,08	0,07	0,02	0,10	0,08	0,06	0,16	0,04	0,04	0,04	0,02	0,05	0,04	0,01	0,03	0,03	0,04	0,06	0,04	0,02	0,02	0,01	0,03	0,02	0,03
CaO	0,87	4,44	0,69	0,47	1,08	0,35	0,58	0,60	1,19	0,27	1,38	1,03	1,28	1,08	0,41	0,8	1,08	0,91	2,93	0,75	0,39	0,31	0,41	0,33	0,46	0,24
Na2O	2,58	3,24	2,23	3,41	2,47	1,65	3,13	1,64	2,86	1,55	2,73	2,85	2,17	3,35	2,29	2,74	3,14	2,55	3,21	3,08	3,28	2,5	2,54	2,53	2,41	2,21
K2O	4,19	2,29	4,30	4,45	3,32	4,21	3,44	4,25	4,18	3,43	4,18	3,14	4,39	4,08	5,83	5,27	4,28	5,39	4,03	2,58	4,37	4,6	4,09	4,02	4,77	5,17
P2O5	0,12	0,25	0,29	0,24	0,15	0,16	0,24	0,17	0,17	0,15	0,18	0,16	0,25	0,19	0,15	0,17	0,17	0,2	0,35	0,2	0,21	0,21	0,21	0,19	0,22	0,12
Loi	1,48	0,81	2,32	1,18	1,74	3,92	3,26	1,76	1,9	1,63	1,43	1,18	1,82	0,82	0,53	1,11	0,85	0,97	1,6	2,47	1,95	1,94	2,43	1,83	1,32	1,1
Total	98,84	99,62	99,68	99,82	100,1	98,73	98,97	99,81	99,80	98,03	99,07	99,28	99,17	99,58	99,45	99,04	99,32	99,31	99,55	99,84	99,97	99,81	99,76	99.88	99,95	99,88
Zr (ppm)	134,1	210,4	238,7	97,20	222,3																					

Table 3

Summary of SHRIMP U-Pb zircon data for the selected samples

		ppm					Isotope ratios							Ages				
Id	Spot(1)(2)	U	Th	$^{206}Pb^*$	% $^{206}Pb_c$	Th/U	$^{207}Pb^*/^{206}Pb^*$	± %	$^{206}Pb^*/^{238}U$	± %	$^{207}Pb^*/^{235}U$	± %	err corr	$^{206}Pb/^{238}U$	±	$^{207}Pb/^{206}Pb$	±	% Disc.
J706-43: Nodular granites																		
15.1	hlc,t2	62	28	24.9	0.01	0.458	0.1824	0.9	0.4643	2.1	11.68	2.2	0.923	2459	42	2675	14	8
15.2	r,t2	452	125	140	--	0.286	0.1529	0.4	0.3596	1.0	7.580	1.1	0.925	1980	18	2378	7.3	17
17.1	c,t2	1347	29	412	--	0.023	0.1222	0.2	0.3561	1.0	6.000	1.0	0.988	1964	17	1988	2.9	1
17.2	hlr,t2	60	40	18.4	--	0.681	0.1235	0.8	0.3556	1.3	6.053	1.5	0.854	1961	22	2007	14	2
17.3	r,t2	424	19	127	--	0.047	0.1215	0.5	0.3487	1.0	5.843	1.2	0.909	1928	17	1978	8.6	3
1.1	c,t2	170	179	20.8	--	1.080	0.0676	1.3	0.1419	1.2	1.323	1.8	0.681	856	9.9	856	27	0
2.1	hlc,t2	95	56	8.1	0.31	0.616	0.0602	2.1	0.0988	1.3	0.820	2.4	0.516	608	7.3	609	45	0
3.1	c,t2	115	77	10.0	--	0.694	0.0611	1.4	0.1011	1.2	0.851	1.9	0.655	621	7.2	642	30	3
6.1	r,t2	3350	1056	299	0.02	0.326	0.0611	0.3	0.1040	1.0	0.876	1.1	0.971	638	6.3	644	5.5	1
9.1	hlc,t2	30	72	2.6	0.22	2.530	0.0610	3.0	0.1013	1.7	0.852	3.4	0.495	622	10	640	64	3
10.1	r,t2	531	170	46.5	0.01	0.331	0.0610	0.7	0.1020	1.1	0.858	1.2	0.847	626	6.3	640	14	2
11.1	r,t2	1069	175	99.7	0.19	0.169	0.0597	0.8	0.1084	1.0	0.891	1.3	0.795	663	6.5	591	17	-12
14.1	r,t2	746	434	67.1	--	0.601	0.0611	1.6	0.1048	1.1	0.883	1.9	0.546	642	6.5	643	35	0
16.1	c,t2	461	207	40.2	0.04	0.465	0.0606	0.7	0.1016	1.1	0.848	1.3	0.826	624	6.3	623	16	0
16.2	hlr,t2	77	59	6.6	--	0.800	0.0610	1.9	0.0995	1.8	0.837	2.6	0.697	611	11	640	40	5
7.1	c,t2	337	104	26.4	--	0.320	0.0588	0.9	0.0912	1.1	0.740	1.4	0.774	563	5.8	560	19	0
13.1	c,t2	626	543	50.7	--	0.897	0.0598	0.6	0.0943	1.1	0.778	1.2	0.855	581	5.9	597	14	3
19.1	t1a	360	182	28.6	0.08	0.521	0.0587	0.9	0.0924	1.5	0.747	1.7	0.868	570	8.1	555	19	-3
20.1	t1a	496	236	39.4	0.09	0.492	0.0589	0.7	0.0924	1.2	0.750	1.4	0.858	570	6.8	563	16	-1
23.1	t1b	921	566	73.2	0.16	0.635	0.0590	0.7	0.0923	1.2	0.751	1.4	0.882	569	6.7	567	14	0
1.2	r,t2	857	40	57.7	--	0.048	0.0578	0.7	0.0784	1.0	0.625	1.2	0.840	487	4.9	523	15	7
4.1	r,t2	523	37	35	--	0.072	0.0585	1.0	0.0780	1.1	0.629	1.5	0.716	484	5	548	23	12
5.1	r,t2	345	33	23	0.03	0.099	0.0566	1.0	0.0776	1.1	0.606	1.5	0.736	482	5.1	475	22	-1
21.1	t1a	334	179	21.1	0.12	0.553	0.0562	1.6	0.0735	1.3	0.570	2.0	0.624	457	5.6	460	35	1
11.2	r,t2	526	26	28.8	0.46	0.052	0.0548	2.0	0.0635	1.1	0.480	2.2	0.481	397	4.1	402	44	1
18.1	r,t2	595	24	28.6	0.07	0.042	0.0539	1.0	0.0559	1.2	0.415	1.6	0.774	350	4.3	368	23	5
3.2	r,t2	1677	15	78.8	0.58	0.009	0.0534	1.2	0.0544	1.0	0.400	1.6	0.641	341	3.4	344	28	1
8.1	t1a	226	175	10	--	0.799	0.0534	1.5	0.0515	1.2	0.378	1.9	0.606	323	3.7	344	34	6

9.2	r,t2	640	78	27.6	0.03	0.126	0.0532	0.9	0.0502	1.1	0.368	1.4	0.749	316	3.3	339	21	7
22.1	r,t2	863	5	36.8	0.02	0.006	0.0525	0.7	0.0496	1.3	0.359	1.4	0.874	312	3.9	306	16	-2
25.1	r,t2	792	3	33.4	0.07	0.004	0.0521	0.8	0.0490	1.2	0.352	1.5	0.833	308	3.7	290	19	-6
24.1	r,t2	1747	3	72.9	0.23	0.002	0.0526	0.7	0.0485	1.2	0.351	1.4	0.877	305	3.7	311	15	2
J809-13: Qtz-Diorite enclaves																		
1.1	t1a	420	43	28.3	0.52	0.105	0.0550	2.3	0.0779	2.4	0.591	3.3	0.718	483	11	412	51	-17
2.1	t1b	1375	68	90.1	0.07	0.051	0.0568	0.9	0.0762	2.3	0.597	2.5	0.935	473	11	485	19	2
3.1	t1b	1122	71	75.1	0.13	0.065	0.0556	1.0	0.0778	2.3	0.597	2.5	0.924	483	11	437	21	-11
4.1	c,t2	1214	174	125	0.06	0.148	0.0623	0.5	0.1195	2.3	1.027	2.4	0.978	728	16	685	11	-6
5.1	t1a	338	58	22.4	0.13	0.178	0.0576	1.4	0.0772	2.4	0.613	2.8	0.856	479	11	514	32	7
J809-15: Crd-Leucogranites																		
1.1	c,t2	640	378	67	0.29	0.61	0.0637	0.9	0.1215	2.5	1.066	2.7	0.929	739	17	730	21	-1
2.1	-	824	1241	31.5	0.27	1.556	0.0525	2.4	0.0444	2.5	0.321	3.4	0.723	280	6.8	308	54	9
3.1	c,t2	1545	314	110	0.43	0.21	0.0588	1.6	0.0827	2.3	0.671	2.8	0.828	512	11	560	34	8
4.1	r,t2	303	147	11.9	0.62	0.502	0.0527	3.3	0.0455	2.6	0.331	4.2	0.625	287	7.4	316	75	9

Errors are 1-sigma; Pbc and Pb* indicate the common and radiogenic portions, respectively. Error in standard calibration was 0.21% (J706-43), 1.18% (J809-13 and J809-15) (not included in the above errors but required when comparing data from different mounts).

Common Pb corrected using measured ^{204}Pb.

(1) c: core; r: rim; hl: high luminosity area.

(2) Zircon types. t1a: Simple acicular parallel banded zircon with high elongation ratio. t1b: Simple euhedral zircon with oscillatory concentric zoning. t2: Zircon composed by an inherited core and external overgrowths.

Highlights:

- Ferrosilicic nodular granites from the Gredos Massif (Central Iberian Zone)
- Cambro-Ordovician protoliths in Variscan high-grade metamorphic complexes
- Cambro-Ordovician ferrosilicic and calc-alkaline arc-back-arc magmatism in the North-Gondwana margin