Age and setting of the Upper Neoproterozoic Narcea Antiform volcanic rocks (NW Iberia)

Edad y significado de las rocas volcánicas del Neoproterozoico Superior del Antiforme del Narcea (NO de Iberia)

G. Gutiérrez-Alonso [1], J. Fernández-Suárez [2] y T.E. Jeffries [3]

[1] Departamento de Geología, Universidad de Salamanca, 33708 Salamanca, Spain
[2] Departamento de Petrología y Geoquímica, Universidad Complutense, 28040 Madrid, Spain
[3] Department of Mineralogy, The Natural History Museum, London SW7 5BD, United Kingdom

ABSTRACT

U-Pb dating of zircons from ryolites intercalated within the Narcea Antiform Neoproterozoic rocks was performed by laser ablation ICP-MS). The age of the ryolite is 559±3 Ma which allows the separation of two different units within the previously established Tineo Series. It is suggested that a terrane-transfer related pull-apart environment could have been the ideal setting for the genesis of these rocks in accordance with previously proposed models for the Neoproterozoic evolution of this region.

RESUMEN

Se han datado mediante U-Pb circones de riolitas intercaladas en las rocas Neoproterozoicas del Antiforme del Narcea, por medio de ablación láser. La edad obtenida es de 559±3 Ma, la cual que permite la separación de dos unidades estratigráficas distintas dentro de las previamente conocidas como Serie de Tineo. Se sugiere que su origen pudiera estar relacionado con cuencas transtensivas relacionadas con la migración de terrenos a lo largo de la evolución Neoproterozoica del margen septentrional de Gondwana.

Key words: *Neoproterozoic, U-Pb dating, 213nm laser ablation ICP-MS, zircon, Iberia, Gondwana.*

Geogaceta, 35 (2004), 79-82
ISSN:0213683X

Introduction

Ancient and modern long-lived continental margins are characterized by a) large transcurrent displacements of terranes related to the stages of oblique plate movements and b) the alternation or switching of processes in time and space according to the coupling or decoupling of subduction; the subduction of active ocean ridges or plumes; or the collision/accretion of minor terranes or oceanic plateaus. Recognizing these features in ancient margins is always challenging, and the precise dating of the related by-products can be the key to decipher the role of the aforementioned processes in the evolution of the margin's architecture.

The NW margin of Gondwana during Neoproterozoic-early Paleozoic times recorded a long-lived active margin in which the above mentioned situations have been recognized (e.g. Murphy and Nance, 1989, Murphy *et al.*, 2000; Fernández Suárez *et al.*, 2000, 2002; Gutiérrez-Alonso *et al.*, 2003; Keppie *et al.*, 2003) and there is a good record of events deduced from the Neoproterozoic magmatic and sedimentary rocks of Western Europe and their transatlantic counterparts. Amongst the best studied realms of the NW Gondwanan margin are the subduction-related terranes that constitute the Neoproterozoic outcrops of western Europe in which back-arc, passive margin and the main arc volcanic-rich sequences have been identified and some tentative evolutionary scenarios have been proposed (e.g. Nagy *et al.* 2002).

In unravelling the paleogeography and the evolution of the NW Gondwanan margin, geochronological techniques have proven to be most useful, not only providing the age of magmatic and metamorphic events in the different terranes, but also as a source of sediment provenance constraints which are extremely useful in reconstructing the terrane architecture of the NW Gondwanan margin.

This paper aims at shedding new light on the timing and nature of the processes that took place in the aforementioned scenario and to constrain the age relationships of the different units that constitute the so called Narcea Series (Fig.1), one of the largest Neoproterozoic outcrops in the West European realm.

Geological background

Within the late Paleozoic West European Variscan Belt (WEVB) there are several exposures of Neoproterozoic rocks recording a pre-Variscan orogenic cycle. One of this extensive outcrops is the Narcea Antiform located in NW Iberia (Fig. 1) where the Carboniferous Variscan deformation gave rise to a complex curved structure where the boundary between the foreland and the hinterland of the WEVB is exposed (Gutiérrez-Alonso, 1992, 1996).

Other Neoproterozoic exposures containing volcanic and volcaniclastic rocks have been described in NW Iberia, in the Villalba Antiform (Martínez Catalán, 1985). In contrast to the abundance of volcanic rocks in the Narcea and Villalba antiform exposures, the extensive outcrops of Neoproterozoic rocks in central Iberia (Fig. 1) seem to contain much less volcanic participation (e.g. Díez Balda, 1980, Rodríguez Alonso, 1985, Valladares *et al.*, 2000) although they are indistinguishable from the NW Iberian Neoproterozoic sedimentary rocks in terms of their respective detrital zircon age populations (Gutiérrez-Alonso *et al.*, 2003).

Within the Narcea Antiform, a sedimentary succession constituted by more than 3000 m of siliciclastic sediments with abundant volcanic participation has been described as the Narcea Series (Lotze, 1956). The base of the succession is not exposed and its top is eroded, being overlain unconformably by Lower Cambrian siliciclastic deposits. The variscan deformation that affects the Narcea Series is very heterogeneous ranging from almost undeformed to intensely sheared rocks where no original features or textures have been preserved. This deformation heterogeneity, the presence of large thrusts with tens of kilometres of displacement, and the lack of distinct levels to correlate the different Neoproterozoic outcrops precludes stratigraphic reconstruction using field relationships and only geochronological data can provide constraints on the possible relationships.

According to the available absolute age dates the westernmost units (known as the Tineo Series (Fig. 1) (Gutiérrez-Alonso and Fernández-Suárez, 1996) are intruded by ca. 600 Ma granitoids (Fernández-Suárez *et al.*, 1998) and their youngest detrital zircons are ca. 640 Ma (Fernández-Suárez *et al.*, 2000) constraining its depositional age between 640 and 600 Ma. On the other hand, the easternmost units (the Narcea Series s.s., Fig. 1) (Gutiérrez-Alonso and Fernández-Suárez, 1996) contain detrital zircons as young as 560 Ma (Gutiérrez-Alonso *et al.*, 2003). In addition, there are areas with abundant volcanic rocks described in the regional literature as "porphyroids" (Gutiérrez-Alonso, 1992; Nieto Fernández, 1998). These volcanic rocks are interpreted to have been generated in a subduction related environment. In this work, one representative sample of these volcanic rocks has been dated by U-Pb (zircon) in order to constrain the age of this volcanic activity. The two main outcrops of these rocks are located in the Cantabrian coast (in the village of Cudillero) and the most extensive area in the vicinity of Tineo (Fig. 1) where a highly stretched, ca 400m thick sequence of volcanic and volcanoclastic rocks is exposed. The sample studied in this work was collected near the top of the Tineo outcrops.

Sample RT was collected in the road between the localities of Tineo and Navelgas (coordinates given in Fig. 1). The sample corresponds to a boudin within the highly strained volcanic rocks that crop out in the surroundings of Tineo. The sampled rock is a deformed ryolite (Fig. 2). The whole volcanic suite ranges from ryolites to andesites including some basalt like units. According to Cuesta *et al.* (2003) the geochemistry of all the Neoproterozoic volcanic rocks of the Narcea Antiform indicates a trend from calc-alcaline crustal magmas to deeper sources with mantelic participation.

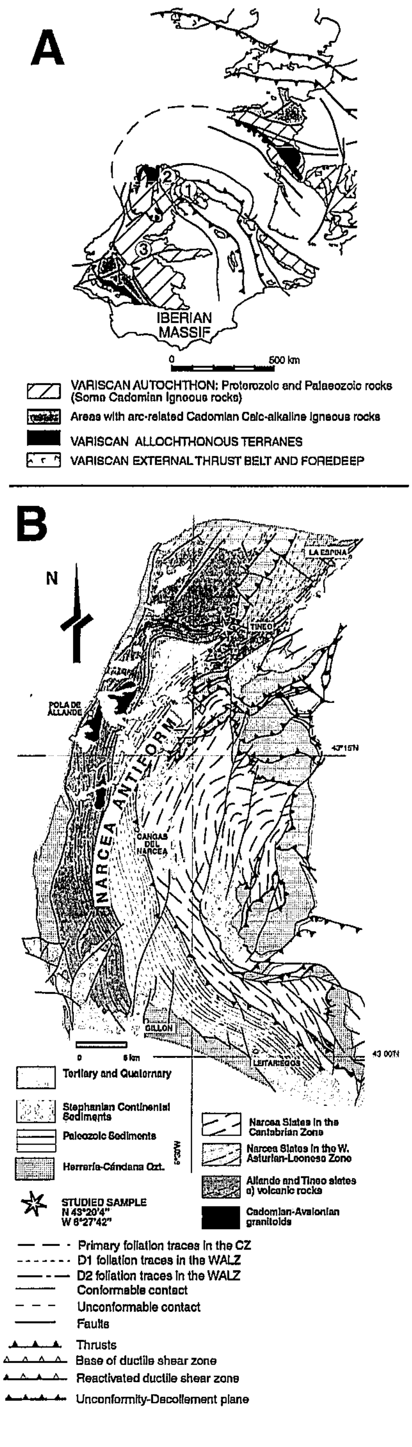

Fig. 1.- A) Geological map of NW Iberia showing the different outcrops of Neoproterozoic rocks and the occurrence of volcanic "porphyroid" suites: (1) Narcea Antiform; (2) Lugo Dome; and (3) the Central Iberian schistose-greywacke rocks. B) Geological map of the Narcea Antiform with the location of the more abundant volcanic rocks and the location of the studied sample (Gutiérrez-Alonso, 1992, 1996).

Fig. 1.- A) Mapa geológico del NO de Iberia mostrando los diferentes afloramientos de rocas Neoproterozoicas la existencia de porfiroides: (1) Antiforme del Narcea; (2) Domo de Lugo; y (3) Complejo esquistoso-grauváquico de la zona Centro Ibérica. B) Mapa geológico del Antiforme del Narcea mostrando las áreas con abundantes rocas volcánicas y la situación de la muestra estudiada (Gutiérrez-Alonso, 1992, 1996)..

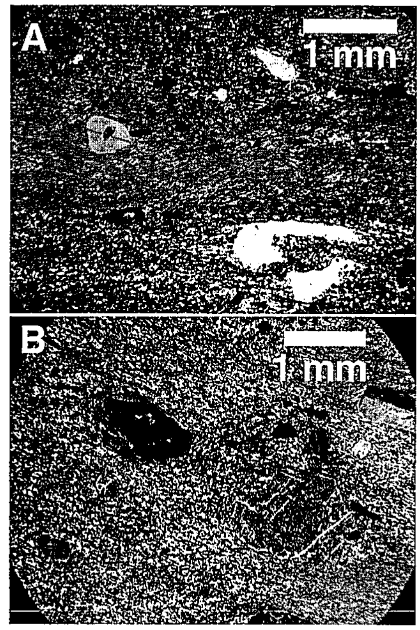

Fig. 2.- Thin section microphotograph of the ryolite dated in this study. Crossed polarizers, A is a section parallel to the stretching lineation and B is normal to it.

Fig. 2.- Microfotografía de la riolita estudiada. Polarizadores cruzados. A corresponde a una sección paralela a lineración de estiramiento y B perpendicular a ella.

U-Pb Analytical Techniques

Zircons were separated at the Complutense University of Madrid using conventional techniques. Zircons were hand-picked in alcohol under a binocular microscope, set in synthetic resin mounts, polished to approximately half their thickness and cleaned in a warm HNO_3 ultrasonic bath. Back-scattered electron (BSE) imaging was performed to ensure that the analysed spots did not straddle different domains.

U-Pb dating of zircons was performed by laser ablation ICP-MS at the Natural History Museum (London). Analytical instrumentation consisted of a UP213 frequency quintupled Nd:YAG based laser ablation system (NewWave Research, Fremont, USA) coupled to a (Thermo Elemental) PQ3, quadrupole based ICP-MS instrument with enhanced sensitivity (S-Option) interface. Instrument and operating parameters used for individual zircon analyses as well as a detailed description of instrumentation, analytical procedures and data reduction are given in detail elsewhere (Fernández-Suárez *et al.*, 2002; Jeffries *et al.*, 2003). Data were collected in one run of 20 analyses, comprising 12 unknowns bracketed before and after by 4 analyses of the standard zircon 91500 (Wiedenbeck *et al.*, 1995). The weighted averages (2σ) of $^{206}Pb/^{238}U$ and $^{207}Pb/^{206}Pb$ ages for the 91500 standard during analyses of the unknowns were respectively 1063.7±3.2 Ma (n=12, certified ID-TIMS $^{206}Pb/^{238}U$ age: 1062.4±0.4 Ma) and 1066±5 Ma (n=12, certified ID-TIMS $^{207}Pb/^{206}Pb$ age: 1065.4± 0.3 Ma).

For each analysis, time-resolved signals were obtained and then carefully studied to ensure that only flat stable signal intervals were included in the age calculations. Given that selection of appropriate signal intervals is critical in obtaining the most accurate and precise ratios for each analysis, the following features were always avoided: i) inclusions of minerals containing U, Th, Pb; ii) U-Th-Pb chemical zonation; iii) alteration or fracture zones with high common Pb, iv) core-rim features; v) inconsistent behaviour of the U-Pb and Th-Pb systems; vi) U-Pb or Th-Pb elemental fractionation (further details are given in Jeffries *et al.*, 2003).

Results

A total of 12 analyses were performed of which we discarded 4 analyses whose time-resolved isotope ratio signals were disturbed, deviating from a flat even profile (see above). The ages reported in Table 1 are not common-lead corrected as ^{204}Pb measurements are rendered useless by the isobaric interference from Hg, a contaminant present in the argon supply gas.

Recently, Andersen (2002) has proposed a common lead correction method that neither uses ^{204}Pb nor assumes concordance, but relies instead on the assumption of coherent behaviour of the U-Pb and Th-Pb systems during Pb loss. Application of this common lead correction algorithm to the analyses reported here does not reveal any significant shift due to common lead (i.e. the age corrections are all within analytical uncertainty).

Based on the above, the best estimate for the crystallisation age of the ryolite is constrained between the pooled concordia age (Ludwig, 1998) of all the analyses reported in Table 1 (Fig. 3a) at 556±4 Ma and the upper intercept age of 560±6 Ma given by a discordia forced through 0 Ma (Fig. 3b). Although both ages overlap within analytical uncertainty, the slightly older upper intercept age is considered a better approximation to the crystallisation age given that 4 of the analyses included in the "concordia age" calculation (i.e. excluding the slightly over-concordant ellipses) have slightly older $^{207}Pb/^{206}Pb$ ages (Table 1 and Fig. 3).

The ^{208}Pb correction method (Ludwig, 2001) was applied to the 5 most concordant analyses of the data set (Table 1) and the weighted average of the ^{208}Pb corrected ages is 559±3 Ma (Fig. 3c), within error of the upper intercept age of 560±6 Ma obtained using the uncorrected ratios.

Discussion

According to the U-Pb age of the studied ryolite (ca. 560 Ma) new constraints can be placed on the Neoproterozoic sequence of NW Iberia and some new ideas on the paleogeography of the Neoproerozoic northern margin of Gondwana can be incorporated to previous hypotheses.

A first conclusion of regional significance is the assignment of the volcanic rocks of the Tineo outcrops to the youngest Neoproterozoic unit within the Narcea Antiform, in contrast with our previous interpretation that considered these rocks to be part of the older sedimentary unit intruded by the ca 600 Ma granitoids. This fact implies the existence of a contact, either stratigraphic (continuous series or an unconformity) or tectonic whose trace is uncertain, binding the two sequences within the westernmost tectonic slice. The high variscan strain present

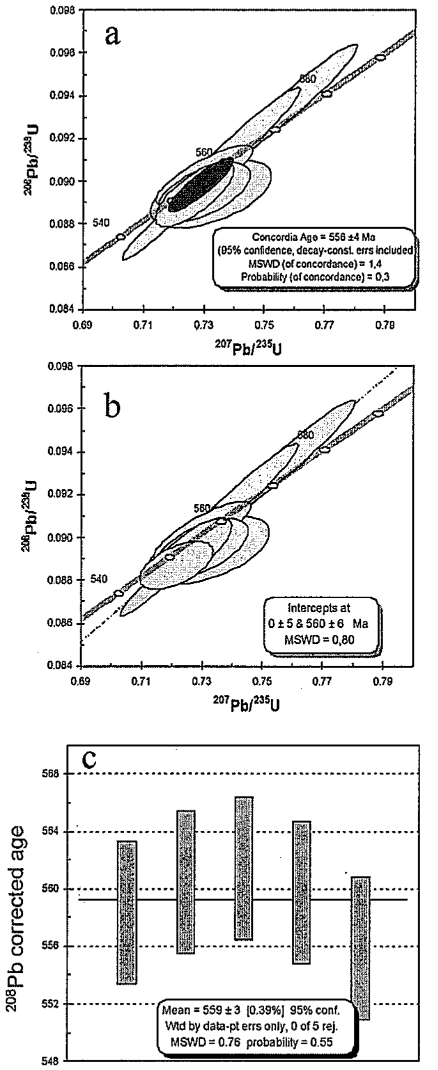

Fig. 3.- A) Wetherill concordia plot of the analyses reported in Table 1. The dark ellipse represents the pooled concordia age (Ludwig, 1998) of the 8 analyses. All error ellipses are 2σ. B) Wetherill concordia diagram showing the upper intercept age given by a discordia line forced through 0±5 Ma. C) Weighted average of the ^{208}Pb corrected (Ludwig, 2001) ages of the 5 most concordant analyses (see text for details).

Fig. 3.- A) Diagrama de concordia de Wetherill de los análisis de la Tabla I. La elipse oscura representa la edad de concordia (Ludwig, 1998) de los 8 análisis. Las elipses representan los errores 2σ. B) Diagrama de concordia de Wetherill mostrando la edad de intersección de una discordia forzada a través de 0±5 Ma. C) Media ponderada de las edades con el contenido en ^{208}Pb corregido (Ludwig, 2001) de los circones más concordantes (detalles en el texto.

Sample RT-And	*Isotopic ratios and 2s (%) errors*									*Ages and 2s absolute errors (Ma)*								*Reported Age [see text for details]*		
Anal. #	$^{206}Pb/^{238}U$	±2σ	$^{207}Pb/^{235}U$	±2σ	$^{207}Pb/^{206}Pb$	±2σ	$^{208}Pb/^{232}Th$	±2σ	$^{238}U/^{232}Th$	$^{206}Pb/^{238}U$	±2σ	$^{207}Pb/^{235}U$	±2σ	$^{207}Pb/^{206}Pb$	±2σ	$^{208}Pb/^{232}Th$	±2σ	Age (Ma)	±2σ	disc%
ja30a05	0,0895	1,28	0,7296	1,72	0,0591	1,42	0,0245	1,42	1,73	553	7	556	7	570	32	489	6	**554**	**6**	3,0
ja30a06	0,0880	1,58	0,7153	1,46	0,0589	0,44	0,0259	0,44	2,80	544	8	548	6	564	10	516	9	**564**	**10**	3,5
ja30a07	0,0903	1,28	0,7296	1,82	0,0586	1,04	0,0247	1,04	2,90	557	7	556	8	552	24	493	9	**557**	**7**	-0,9
ja30a14	0,0894	1,40	0,7265	1,46	0,0589	1,02	0,0235	1,02	1,42	552	7	554	6	562	22	468	7	**554**	**6**	1,8
ja30b06	0,0938	2,34	0,7592	2,28	0,0587	0,64	0,0236	0,64	2,39	578	13	574	10	554	14	472	15	**554**	**14**	-4,3
ja30b07	0,0918	2,36	0,7413	2,22	0,0586	0,62	0,0244	0,62	3,79	566	13	563	10	550	14	487	13	**559**	**8**	-2,9
ja30b08	0,0887	1,06	0,7210	1,38	0,0589	1,16	0,0207	1,16	1,76	548	6	551	6	564	26	415	13	**550**	**5**	2,8
ja30b09	0,0894	1,46	0,7317	2,24	0,0593	1,92	0,0249	1,92	2,16	552	8	558	10	578	42	497	13	**554**	**7**	4,5

Table I.- Analytical results and age of the analysed zircons.

Table I- Resultados analíticos y edad de los circones analizados.

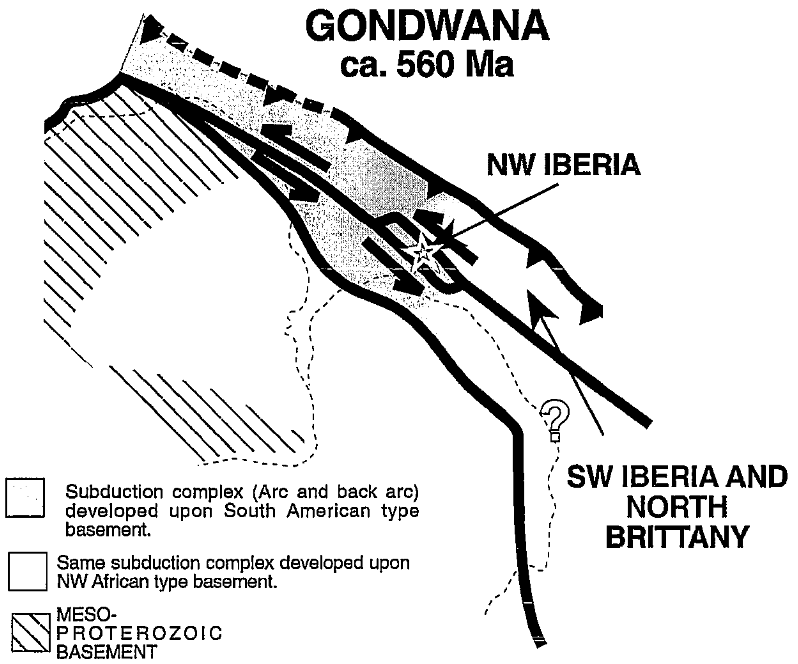

Fig. 4.- Temptative scenario proposed for the origin of the studied Neproterozoic ryolites (based in Fernández-Suárez et al., 2002 and Gutiérrez-Alonso et al. 2003).

Fig. 4.- Propuesta tentativa de un escenario global para la génesis de las riolitas neoproterozoicas estudiadas. (Basado en Fernández-Suárez* et al.*, 2002 y Gutierrez-Alonso* et al. *2003).

in these rocks and the lack of other diagnostic lithologies make it impossible to ascertain, with the available data, whether this contact is stratigraphic or tectonic in origin.

The significance of the age obtained in this study is in agreement with previous scenarios that have been proposed for the northern margin of Gondwana during the Neoproterozoic, a subduction related setting (Murphy *et al.* 2000; Fernández-Suárez *et al.*, 2000; Keppie *et al.*, 2003; Gutiérrez-Alonso *et al.*, 2003) with margin parallel terrane transfer (Fernández-Suárez *et al.*, 2002; Gutiérrez-Alonso *et al.* 2003) in a manner similar to the recent history of the western margin of North America. Within this context, the studied rocks can be considered to have been generated either in the main subduction arc edifice or in a minor basin, possibly of pull-apart type and related to transcurrent terrane motions along the margin (e.g. Gutiérrez-Alonso *et al.*, 2003). If the first possibility is considered, then one would expect a much larger volume of coeval volcanic and plutonic rocks in the region than actually exist (see also Fernández-Suárez *et al.*, 1998). The latter interpretation (a small basin) would be favoured by the scarcity of volcanic rocks, although no Neoproterozoic structures have been identified in the region. Another argument in favour of the latter hypothesis is that it fits the scenario proposed on the basis of independent data (Fig. 4). From this point of view, a model based in older interpretations of the evolution of this margin in Neoproterozoic times would link these volcanic rocks with a small basin related to back-arc subduction in a fashion similar to models proposed for coeval volcanic rocks in northern Brittany (Chantraine *et al.* 1998).

Conclusions

The age of the dated ryolite is 559±3 Ma which allows the separation of two different units within the previously established Tineo Series, the Allande Series, intruded by 600 Ma granitoids and the Tineo Series s.s. which includes the studied volcanic rocks.

Although a general subduction environment must be the setting for the generation of the studied rocks, we suggest that a terrane-transfer related pull-apart environment could be the ideal location for the genesis of these rocks within the aforementioned general setting and in accordance with previously proposed models for the Neoproterozoic evolution of this region.

Acknowledgements

Funding was provided by project BTE2000-1490-C02-01 of the Spanish Ministry of Education. The Electron Microscopy and Mineral Analysis Division is kindly acknowledged for technical and logistic support. This paper is a contribution to IGCP project 453

References

Andersen, T. (2002): *Chem. Geol.*, 192, 59-79.
Chantraine, J.; Chauvel, J.J.; Balé, P., Denis, E. and Rabu, D. (1988): *Bull. Soc. Geol. France*, IV, 5, 815-829.
Cuesta, A., Gallastegui, G., Suárez, O. and Rubio Ordoñez, A. (2003): IV Congreso de Geoquímica, Coimbra, 2003.
Díez Balda, M.A. (1980): *Estud. Geol.*, 36, 131-138.
Fernández Suárez, J., Gutiérrez-Alonso, G., Jenner, G.A. and Jackson, S.E. (1998): *Can. Jour. Earth Sci.* 35, 1439-1453.
Fernández Suárez, J., Gutiérrez-Alonso, G., and Jeffries, T.E. (2002): *Earth Planetary Sci. Lett.*, 204, 75-88.
Fernández Suárez, J., Gutiérrez-Alonso, G., Jenner, G.A. and Tubrett, M.N. (2000): *Precambrian Research*, 102, 185-206.
Gutiérrez-Alonso, G. (1992): Tesis Doctoral, Universidad de Oviedo, 317 pp.
Gutiérrez-Alonso, G. (1996): *J. Struct. Geol.*, 18, 1217-1229.
Gutiérrez-Alonso, G.and Fernández Suárez, J. (1996): *Rev. Soc. Geol. Esp.*, 9, 227-239.
Gutiérrez-Alonso, G., Fernández Suárez, J., Jeffries, T.E., Jenner, G.A., Tubrett, M.N., Cox, R. and Jackson, S.E. (2003): *Tectonophysics*, 365, 221-232.
Jeffries, T.E., Fernández Suárez, J., Corfú, F., Gutiérrez-Alonso, G. (2003): *J. Anal. At. Spectrom.*, 18, 847-855.
Keppie., J.D., Dostal, J., Cameron, K.L., Solari, L.A., Ortega-Gutiérrez, F. and Lopez, R. (2003): *Precambrian Research*, 120, 365-389
Lotze, F. (1956): *N. Jahr. Geol. Palaont.*, 8, 373-380.
Ludwig, K.R. (1998): *Geochim. Cosmochim. Acta*, 62, 665-676.
Ludwig, K.R. (2001): Isoplot/Ex versión 2.49. Berkeley Geochronology Center Spec. Publ. 1, 55 pp.
Martínez Catalán, J.R. (1985): *Corpus Geologicum Gallaeciae*, 2, 291 pp.
Murphy, J.B and Nance, D.R. (1989): *Geology*, 17, 735-738.
Murphy, J.B., Strachan, R.A., Nance, R.D., Parker, K.D. and Fowler, M.B. (2000): *Geology*, 28, 1071-1074
Nagy, E.A., Samson, R.S. and D'Lemos, R.S.(2002): *Precambrian Research*, 116, 1-17.
Nieto Fernández, F.J. (1998): Tesis de Licenciatura, Universidad de Oviedo, 81 pp.
Rodríguez Alonso, M.D. (1985): *Acta Salmanticensia*, 51
Valladares, M.I., Barba, P., Ugidos, J.M., Colmenteo, J.R. and Armenteros, I. (2000): Intl. *Jour. Earth Sci.*, 89, 2-20.
Wiedenbeck, M., Allé, P., Corfú, F., Grifin, W.L., Meier, M., Orbeli, F., von Quadt, A., Roddick, J.C. and Spiegel, W. (1995): *Geostand. Newsl.*, 19, 1-23.