Geologica Acta, Vol.6, Nº 4, December 2008, 313-317
DOI: 10.1344/105.000000259
Available online at www.geologica-acta.com

A revised Ordovician age for the Sisargas orthogneiss, Galicia (Spain). Zircon U-Pb ion-microprobe and LA-ICPMS dating

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ABSTRACT

The Sisargas orthogneiss is located in the Schistose Domain of the Galicia Trás-Os-Montes Zone. It has previously been dated by Allegret and Iglesias (1987) who reported an U-Pb upper intercept at 570 ± 14 Ma, considered to be the crystallization age. For this reason, the Sisargas orthogneiss has traditionally been considered one of the oldest magmatic rocks of the Central Iberian Zone. However, new SIMS and LA-ICPMS data reveal that it crystallized at 479 ± 7 Ma and contains zircons with abundant pre-magmatic cores with ages clustering at 585 ± 15 Ma. This suggests that the Sisargas orthogneiss derives from the melting of a Pan-African protolith.

KEYWORDS | **U-Pb dating. Zircon. Sisargas orthogneiss. Iberian Massif.**

INTRODUCTION

The Galicia Trás-os-Montes Zone (GTMZ) of the Iberian Massif is located in the northwest of the Iberian Peninsula, thrust over the Central Iberian Zone. It is formed by two superimposed domains: The Schistose Domain and the Allochthonous Complexes Domain (Farias et al., 1987; Arenas et al., 1988) (Fig. 1). The Schistose Domain is situated in the lower part of the GTMZ and is mainly composed of Paleozoic materials and magmatic rocks of essentially felsic composition. The Allochthonous Complexes are situated on top of the Schistose Domain and constitute a superposition of allochthonous units which were displaced long distances and were part of extensive accumulation of nappes (Ries and Shackleton, 1971). These units are composed of ophiolitic materials with arc and oceanic origin and terrains of continental affinity (Arenas et al., 1986; Martínez Catalán et al., 1997, 1999).

The Sisargas orthogneiss is the northernmost part of a north-south band that is generally formed by two-mica augen orthogneisses and crops out in the Schistose Domain and spreads out from San Adrian Cape and the Sisargas Islands, in the north, to Pontevedra in the south (Fig. 1).

The Sisargas orthogneiss has previously been dated by Allegret and Iglesias (1987) using the conventional U-Pb method. The data obtained by these authors were highly discordant and defined a discordia with an upper intercept at 570 ± 14 Ma, which they considered to represent the crystallization age. For this reason, the Sisargas orthogneiss and the Miranda do Douro orthogneiss (crystallization age 618 ± 9 Ma, Lancelot et al., 1985) were considered the oldest magmatic rocks of the Central Iberian Zone.

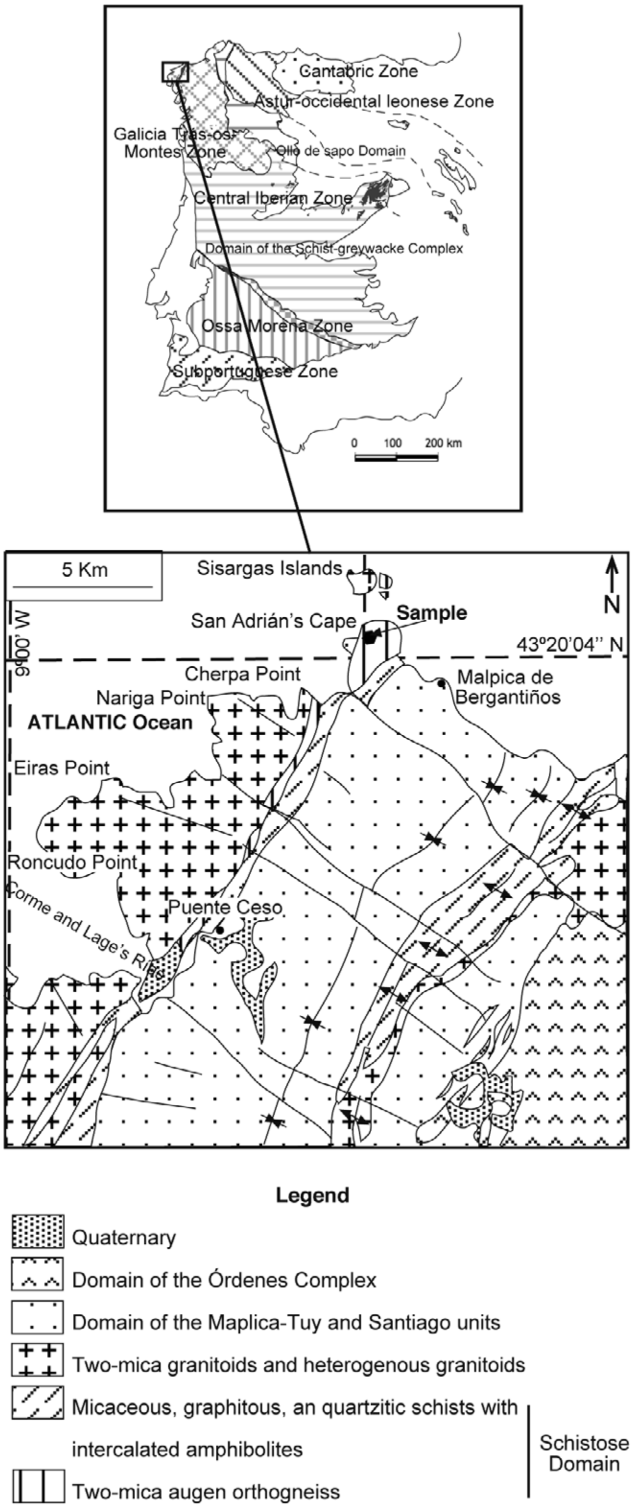

FIGURE 1 | **Geological scheme of the Sisargas area. The geological scheme represents a section of the geological map of Santiago de Compostela (González-Lodeiro et al., 1984).**

Recently, Bea et al. (2006) revised the age of the Miranda do Douro orthogneiss using cathodoluminescence imaging and single zircon U-Pb microanalysis. The authors obtained a crystallization age of 483 ± 3 Ma and concluded that the upper intercept at 618 ± 9 Ma (Lancelot et al., 1985) reflected the fact that about 70-80% of zircon grains contained pre-magmatic restitic cores (see also Bea et al., 2007), the age of which clustered around 605 Ma, very close to the 618 Ma age of Lancelot et al. (1985).

For this reason, we decided to investigate the crystallization age of the Sisargas orthogneiss using the same methodology, i.e. cathodoluminiscence imaging and single zircon U-Pb spot analysis.

SISARGAS ORTHOGNEISS

The Sisargas orthogneiss is a coarse grained biotite-bearing augen-gneiss, variably deformed and intensively metamorphosed. The augens consist of K-feldspar and synneusis of plagioclase crystals, which are set into a fine-grained groundmass of quartz, plagioclase, K-feldspar and biotite. Muscovite, zircon, apatite, monazite, xenotime and oxides appear as accessory phases. Under the microscope, the gneiss presents an allotriomorphic granular texture, with myrmekitic intergrowths and a foliation marked by micas. Its chemical composition corresponds to a slightly sub-aluminous granite with SiO_2≈72-73%, CaO≈0.8-0.9, Na_2O≈3.2-4.0%, K_2O≈5.3-5.5% and alumina saturation index (ASI)≈0.95-1.01.

METHODS

One sample of about 10-15 kg was collected for zircon geochronology. Zircons were separated using conventional magnetic and heavy-liquid techniques. Crystals were mounted, polished and studied by cathodoluminiscence imaging under the scanning electron microscope (SEM) at the University of Granada prior to the ion microprobe (SIMS) and laser ablation ICP MS (LA-ICPMS) analysis.

Twelve U-Th-Pb analyses were done on seven grains using a Cameca IMS-1270 ion microprobe at the Nordsim facility in Stockholm (Table 1). Analytical methods broadly follow those described by Whitehouse

TABLE 1 | **U-Pb ion-microprobe and LA-ICPMS data of zircon grains from the Sisargas orthogneiss. For grains with the same reference, the characters “c” and “b” mean core and rim, respectively.**

Grain	U (ppm)	Th (ppm)	Pb (ppm)	$^{207}Pb/^{206}Pb$ measure	s(%)	$^{206}Pb/^{238}U$ measure	s(%)	$^{206}Pb/^{238}U$ (Ma)	$^{207}Pb/^{235}U$(Ma)	$^{207}Pb/^{206}Pb$ (Ma)	206Pb/238U (Ma. 207 corr)
Laser-Ablation ICPMS data											
z1	304	102	31	0.0587	2.17	0.09659	2.93	594.4	586.5	556.1	595.1 ± 17.3
z5	509	237	51	0.06157	1.65	0.0932	5.71	574.4	591.9	659.3	572.7 ± 30.8
z26	440	292	38	0.05981	3.28	0.07586	4.01	471.4	493.3	596.7	469.4 ± 18.8
z29	1730	1105	108	0.05974	6.01	0.07832	4.84	486.1	505.5	594.1	484.3 ± 23.8
z30	713	261	45	0.06004	8.72	0.09594	4.73	590.6	593.6	605.1	590.3 ± 29.4
z32	416	125	42	0.05731	5.88	0.07544	3.3	468.8	474.8	503.5	468.3 ± 16.4
z39	538	97	41	0.05856	4.23	0.07875	2.99	488.7	499.7	550.7	487.6 ± 15.2
z40	580	358	47	0.05609	18.24	0.07517	9.54	467.2	465.3	455.9	467.4 ± 44.4
Ion-microprobe data											
z40b	861.5	35.5	70.4	0.056506	0.43	0.0765035	0.73	475.2	474.7	472.3	475.3 ± 3.6
z40c	244.7	15.7	19.8	0.056765	0.8	0.0751405	0.73	467.1	469.7	482.5	466.8 ± 3.5
z41b	657.7	45.9	54.5	0.056302	0.79	0.077123	0.94	478.9	476.4	464.3	479.2 ± 4.7
z41c	490	31.1	41.1	0.056595	0.72	0.0778465	0.92	483.3	482	475.9	483.4 ± 4.6
z45b	649	49.5	54.1	0.05625	0.62	0.077394	0.92	480.5	477.4	462.3	480.8 ± 4.4
z47b	395.5	118.7	34.7	0.056574	0.85	0.076393	0.72	474.6	474.6	474.9	474.5 ± 3.5
z47c	236.3	22.4	19.5	0.057037	0.83	0.0760664	0.68	472.6	476.1	492.9	472.3 ± 3.3
z50b	702.2	46.6	56.3	0.057305	0.63	0.0747703	1.38	464.8	471.4	503.3	464.3 ± 6.4
z50c	73.5	39.6	8.7	0.062585	1.73	0.0956471	0.72	588.8	611	694.1	586.6 ± 4.8
z51c	1372.3	188.1	121	0.056686	0.4	0.0805685	1.5	499.5	495.9	479.3	499.9 ± 7.3
z52	376.9	29	30.9	0.056958	0.51	0.0785848	1.39	487.7	488.1	489.9	487.6 ± 6.7
z52b	1163.1	1143.7	124.5	0.05748	0.77	0.0760133	1.39	472.3	478.8	510.1	471.7 ± 6.6

et al. (1999 and references therein). U/Pb ratios were calibrated using the Geostandard 91500 reference zircon (1065 Ma; Wiedenbeck et al., 1995) and include a propagated error component from replicate analyses of 91500 during the analytical session. Errors on $^{207}Pb/^{206}Pb$ ratios are either the observed analytical uncertainly or the counting statistics error, whichever is highest.

Eight U-Pb analyses were carried out on eight grains using a LA-ICPMS system at the University of Granada (Table 1). The LA-ICPMS system is an Agilent-7500 spectrometer with a 213 nm Nd-YAG Merchantek laser unit. Ablation was performed in a He atmosphere with a 60 μm diameter laser beam and a repetition rate of 5 Hertz. Spots were pre-ablated during 60 seconds with a laser energy of 50%, ablation was done for 90 s with a laser energy of 75% moving the sample stage upwards 5 μm every 30 seconds. The glass NIST-610 (409 ppm Pb, 460 ppm U) was used as an external standard. The following isotope ratios, determined by TIMS at the University of Granada, were also used: $^{204}Pb/^{206}Pb$ = 0.06, $^{207}Pb/^{206}Pb$ = 0.9127, $^{208}Pb/^{206}Pb$ = 2.1898, $^{206}Pb/^{238}U$ = 0.2501 and $^{208}Pb/^{232}Th$ = 0.5402. The coefficient of variation on 12 replicates of NIST-610 measured in the same session was ± 2.4% for $^{206}Pb/^{238}U$ and ± 0.3% for $^{207}Pb/^{206}Pb$. The accuracy was estimated by comparing the results of analyzing the same population of very uniform grains from a diorite with the Nordsim (307 ± 3 Ma) and the LA-ICPMS (309 ± 9 Ma). Common-Pb corrections assumed that most contaminant Pb is present on the surface of the grains or in the resin, and has a composition that can be approximated using the Stacey and Kramers (1975) model for the present day.

All ages were calculated using the decay constant recommendations of Steiger and Jäger (1977).

RESULTS AND DISCUSSION

Seventy six zircons were studied by SEM cathodoluminiscence imaging. Most of the zircons present typical magmatic oscillatory zoning, in places with a

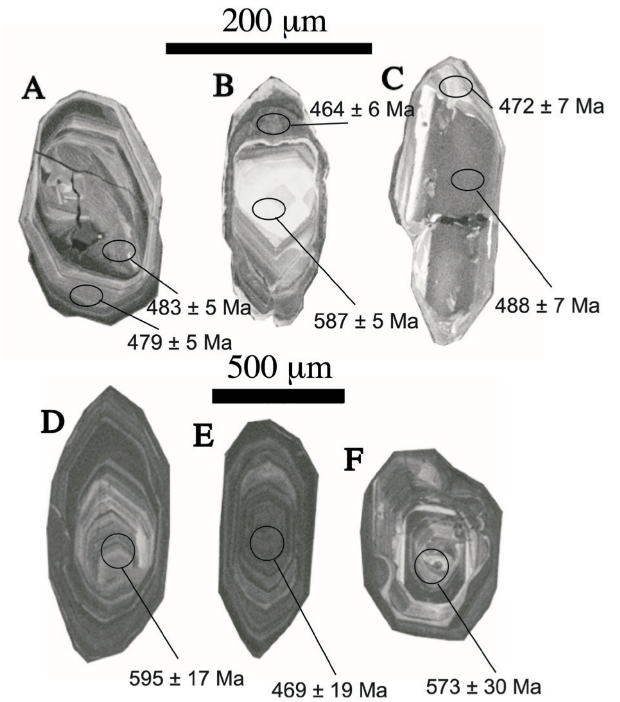

FIGURE 2 | **Cathodoluminescence images of selected zircons from the Sisargas orthogneiss. A, B and C have been dated by ion microprobe and D, E and F have been dated by LA-ICPMS.**

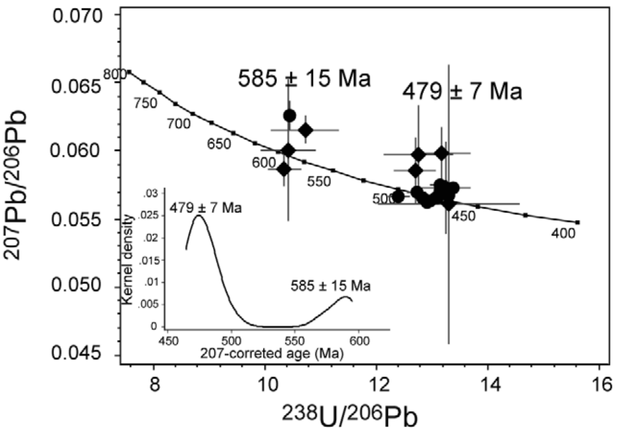

FIGURE 3 | **Tera-Wasserburg plot. Circles represent ion-microprobe data and diamonds represent LA-ICPMS data.**

convolute zoned inner part. About 35% of the crystals contain discordant restitic cores (Fig. 2, zircons B, D, and F).

The zircons were analysed by the U-Pb method using SIMS and LA-ICPMS. Results are shown in Table 1 and U-Pb data plotted in a Tera-Wasserburg diagram (Fig. 3). These data reveal the presence of two concordant or nearly concordant populations: one around 480 Ma and the other around 580 Ma.

The first population is, by far, the most abundant (Fig. 3) and was obtained from zircons with uniform zoning without inherited cores and from rims of zircons that containing inherited cores. The most concordant data of this population (1.01 > ^{206}Pb/^{238}U age / ^{207}Pb/^{235}U age > 0.99) yielded a mean age of 479 ± 7 Ma (95% of confidence interval). The second population appears only in inherited cores of some zircons yielding a mean age of 585 ± 15 Ma (95% of confidence interval).

The age data are interpreted in the following way: The most abundant and concordant population, with an age of 479 ± 7 Ma, is interpreted to represent the crystallization age of the Sisargas orthogneiss. This age is similar to crystallization ages of other Ordovician orthogneisses of the Central Iberian Zone (Valverde-Vaquero et al., 2000; Bea et al., 2006; Montero et al., 2007), but differs from the Ediacaran age proposed by Allegret and Iglesias (1987).

We suggest that the less abundant, also concordant, population with an age of 585 ± 15 Ma, represents the age of the protolith which produced the magma that subsequently crystallized to form the pre-Sisargas orthogneiss granite. This protolith would have been formed of Pan-African rocks which were involved in the Cambro-Ordovician magmatism of the Central Iberian Zone. This interpretation seems sound because Iberia was attached to the northern margin of Gondwana during Pan-African times (Gutiérrez-Marco et al., 2002).

CONCLUSIONS

The Sisargas orthogneiss, located in the Schistose Domain of the Galicia Trás-Os-Montes Zone, is not one of the oldest magmatic rocks of Iberia. According to our data, this gneiss has a crystallization age of 479 ± 7 Ma, which fits well with ages obtained for other Cambro-Ordovician gneisses from the Central Iberian Zone (Valverde-Vaquero et al., 2000; Bea et al., 2006; Montero et al., 2007).

A population of restitic cores with mean age of 585 ± 15 Ma, represents zircons that were not totally dissolved during the Cambro-Ordovician magmatism. Their presence suggests that the magmatic source of the Sisargas orthogneiss was formed from Pan-African rocks.

Finally, we conclude that the upper intercept of Allegret and Iglesias (1987) at 570 ± 14 Ma does not represent the crystallization age of the Sisargas orthogneiss but instead, indicates the presence of zircons with abundant inherited cores of Ediacaran age.

ACKNOWLEDGMENTS

We are indebted to J.H. Scarrow for her assistance with the English. This work was financially supported by the Spanish grant CLG2005-05863/BTE and the Andalucian grant RNM1595. This is the Nordsim publication nº 209. The Nordsim facility is operated and financed under a contract between the research funding agencies of Denmark, Norway and Sweden, the Swedish Museum of Natural History and the Geological Survey of Finland.

REFERENCES

Allegret, A., Iglesias Ponce de León, M., 1987. U-Pb dating of Sisargas Orthogneiss (Galicia, NW-Spain); new evidence of a Precambrian basement in the northwestern part of the Iberian Peninsula. Neues Jahrbuch fuer Mineralogie. Monatshefte, 8, 355-368.

Arenas, R., Gil Ibarguchi, J.I., González Lodeiro, F., Klein, E., Martínez Catalán, J.R., Ortega Gironés, E., Pablo Maciá, J.G., Peinado, M., 1986. Tectonostratigraphic units in the complexes with mafic and related rocks of the NW of the Iberian Massif. Hercynica, 2, 87-110.

Arenas, R., Farias, P., Gallastegui, G., Gil Ibarguchi, J.I., González Lodeiro, F., Klein, E., Marquínez, J., Martín Parra, L.M., Martínez Catalán, J.R., Ortega, E., Pablo Maciá, J.G., Peinado, M., Rodríguez-Fernández, L.R., 1988. Características geológicas y significado de los dominios que componen la Zona de Galicia-Tras-os-Montes. Simposio sobre Cinturones Orogénicos. II Congreso de Geología de España, Granada, Volumen Simposios, 75-84.

Bea, F., Montero, P., Talavera, C., Zinger, T., 2006. A revised Ordovician age for the Miranda do Douro orthogneiss, Portugal. Zircon U-Pb ion-microprobe and LA-ICPMS dating. Geologica Acta, 4, 395-401.

Bea, F., Montero, P., González-Lodeiro, F., Talavera, C., 2007. Zircon inheritance reveals exceptionally fast crustal magma generation processes in Central Iberia during the Cambro-Ordovician. Journal of Petrology, 48, 1227-2339.

Farias, P., Gallastegui, G., González Lodeiro, F., Klein, E., Marquínez, J., Martín Parra, L.M., Martínez Catalán, J.R., Pablo Maciá, J.G., Rodríguez-Fernández, L.R., 1987. Aportaciones al conocimiento de la litoestratigrafía y estructura de Galicia Central. Memorias - Museu e Laboratorio Mineralogico e Geologico, Faculdade de Ciencias, Universidade do Porto, 1, 411-431.

González Lodeiro, F., Hernández Urroz, J., Martínez Catalán, J.R., Naval Balbín, A., Ortega Gironés, E., De Pablo Macía, J.G., 1984. Mapa geológico de España Escala 1:50.000 nº 94 (Santiago de Compostela). Segunda Serie-Primera Edición. Instituto Geológico y Minero de España. Madrid.

Gutiérrez-Marco, J.C., Robardet, M., Rábano, I., Sarmiento, G.N., San José-Lancha, M.A., Herranz, P., Pieren Pidal, A.P., 2002. Ordovician. In: Gibbons, W., Moreno, T. (eds.). The Geology of Spain. London, Geological Society, 31-49.

Lancelot, J., Allegret, A., Iglesias Ponce de León, M., 1985. Outline of upper Precambrian and lower Paleozoic evolution of the Iberian Peninsula according to U-Pb dating of zircons. Earth and Planetary Science Letters, 74, 325-337.

Martínez Catalán, J.R., Arenas, R., Díaz García, F., Abati, J., 1997. Variscan accretionary complex of northwest Iberia: Terranes correlation and succession of tectonothermal events. Geology, 25, 1103-1106.

Martínez Catalán, J.R., Arenas, R., Díaz García, F., Abati, J., 1999. Allocthonous units in the Variscan belt of NW Iberia (Terranes and Accrecionary History). In: A.K. Sinha, (ed.). Basement Tectonics, 13. Dordrecht, Kluwer Academic Publishers, 65-84.

Montero, P., Bea, F., González-Lodeiro, F., Talavera, C., Whitehouse, M.J., 2007. Zircon ages of metavolcanic rocks and metagranites of the Ollo de Sapo Domain in Central Spain: implications of Neoproterozoic to Early Paleozoic evolution of Iberia. Geological Magazine, 144(6), 963-976.

Ries, A.C., Shackleton, R.M., 1971. Catazonal Complexes of North-West Spain and North Portugal, remants of Hercynian thrust plate. Nature Physical Sciences, 234, 65-68.

Stacey, J.S., Kramers, J.D., 1975. Approximation of terrestrial lead isotope evolution by a two-stage model. Earth and Planetary Science Letters, 26, 207-221.

Steiger, R.H., Jäger, E., 1977. Subcommision on Geochronology. Convention on the use of decay constants in geo- and cosmochronology. Earth and Planetary Science Letters, 36, 359-362.

Valverde-Vaquero, P., Dunning, G.R., 2000. New U-Pb ages for Early Ordovician magmatism in Central Spain. Journal of Geological Society, 157, 15-26.

Whitehouse, M.J., Kamber, B.S., Moorbath, S., 1999. Age significance of U-Th-Pb zircon data from early Archean rocks of west Greenland - a reassessment based on combined ion-microprobe and imaging studies. Chemical geology, 160, 201-224.

Wiedenbeck, M., Allé, P., Corfu, F., Griffin, W.L, Meier, M., Oberli, F., Von Quadt, A., Roddick, J.C., Spiegel, W., 1995. Three natural zircon standards for U-Th-Pb Lu-Hf trace element and REE analysis. Geostandards Newsletter, 19, 1-23.

Manuscript received December 2007;
revision accepted May 2008;
published Online August 2008.