Geochemical and isotopic (Sr, Nd) constraints on the origin of the calc-alkaline syn-orogenic association from the Anatectic Complex of Toledo (Hercynian Iberian Belt)

Implicaciones geoquímicas e isotópicas (Sr, Nd) en el origen de la asociación calco-alcalina sin-orogénica del Complejo Anatéctico de Toledo (Orógeno Hercínico Ibérico)

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RESUMEN

Los nuevos datos químicos e isotópicos (Sr, Nd) de los gabros sin-orogénicos (previos al pico metamórfico) de afinidad shoshonítica (gabros de Toledo) y de los también sin-orogénicos granitoides de Argés revelan la presencia de una marcada heterogeneidad isotópica en estas rocas. Este hecho contrasta con la homogeneidad y la signatura isotópica mantélica mostrada por otra de las series gabroideas del área (gabros tipo La Bastida) a pesar de que se trata de rocas que son también contemporáneas con los citados gabros de Toledo y granitos de Argés, y están también ligados espacialmente a éstos. La afinidad shoshonítica de los gabros de Toledo podría estar relacionada con algún tipo de interacción hidrotermal a escala local con fluidos (¿magmáticos?) relacionados con los granitoides de Argés, lo cual podría también explicar la presencia de las heterogeneidades isotópicas en los citados gabros de Toledo así como en las variedades intemedias de la serie de Argés.

ABSTRACT

New chemical and isotopic (Sr, Nd) data obtained for the syn-orogenic (pre-metamorphic climax) shoshonitic affinity gabbros (Toledo type) and Argés calc-alkaline affinity granitoids indicate the presence of a marked isotopic heterogeneity. This contrasts with the other gabbroic series of the area (La Bastida gabbros) which in spite of the fact that they are spatially and temporally related to the Toledo gabbros and the Argés granites, are isotopically homogeneous and have a more mantle-like signature. The shoshonitic affinity of the Toledo gabbros could be produced by local-scale interaction with hydrothermal (magmatic?) fluids related to the Argés granites; this may also explain the presence of the isotopic heterogeneities in the Toledo gabbros and also in the intermediate members of the Argés series.

Key words: *Isotopic heterogeneity, shoshonitic affinity gabbros, syn-orogenic Hercynian plutonism*

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Introduction

In the Anatectic Complex of Toledo (hereafter ACT) Hercynian magmatism is essentially syn-orogenic. With respect to the metamorphic peak granites from this area can be classified into two categories: (1) Pre-metamorphic peak granitoids and (2) Anatectic granites which are synchronous with the metamorphic climax. Within the pre-metamorphic peak granitoids it is possible to distinguish two types: calc-alkaline affinity granites with associated minor basic rocks (Argés granites and La Bastida and Toledo type gabbros) and strongly peraluminous granites (Moncloa type). The basic and acid types are intimately associated from a spatial and age point of view. The second group of anatectic granites is composed of several varieties, the most important of which are the Cervatos leucogranites and the Layos restite-rich granitoids (Barbero 1992; Barbero and Villaseca, 1992; Barbero *et al.*, 1995).

The conditions of the metamorphic climax of the ACT have been estimated at temperatures of 800-850° C and pressures between 4-6 kbar on the bases of paragenetic studies in the metamorphic country rock granulites and pre-metamorphic peak granitoids. This high-T/low-P metamorphism is more extreme than in other nearby Hercynian areas, and could be related to the ascent of mantle-derived magmas in an orogenic extensional regime. Partial melting was synchronous with this extension leading to the generation of anatectic granites (Barbero, 1994).

The age of the metamorphic climax was probably around 341±8 Ma as estimated by a Sm-Nd garnet-whole-rock isochron made in the Argés granites which coincides, within error with a K-Ar hornblende age of 342±7 Ma gave for the orthoamphibolites from the Sierra de Guadarrama (Barbero *et al.*, 1995). Andonaegui (1990) note that Rb-Sr whole-rock geochronology of the Argés granitoids was problematic because of the isotopic heterogeneity found in these granites; this will be discussed later in this work.

Barbero *et al.*, (1990) studied the origin of the calc-alkaline syn-orogenic association of the ACT, and, based on geochemical features, reached several conclusions: First, it seems that both types of gabbros associated with the Argés granitoids (La Bastida and Toledo gabbros; G1 and G2 gabbros of Barbero *et*

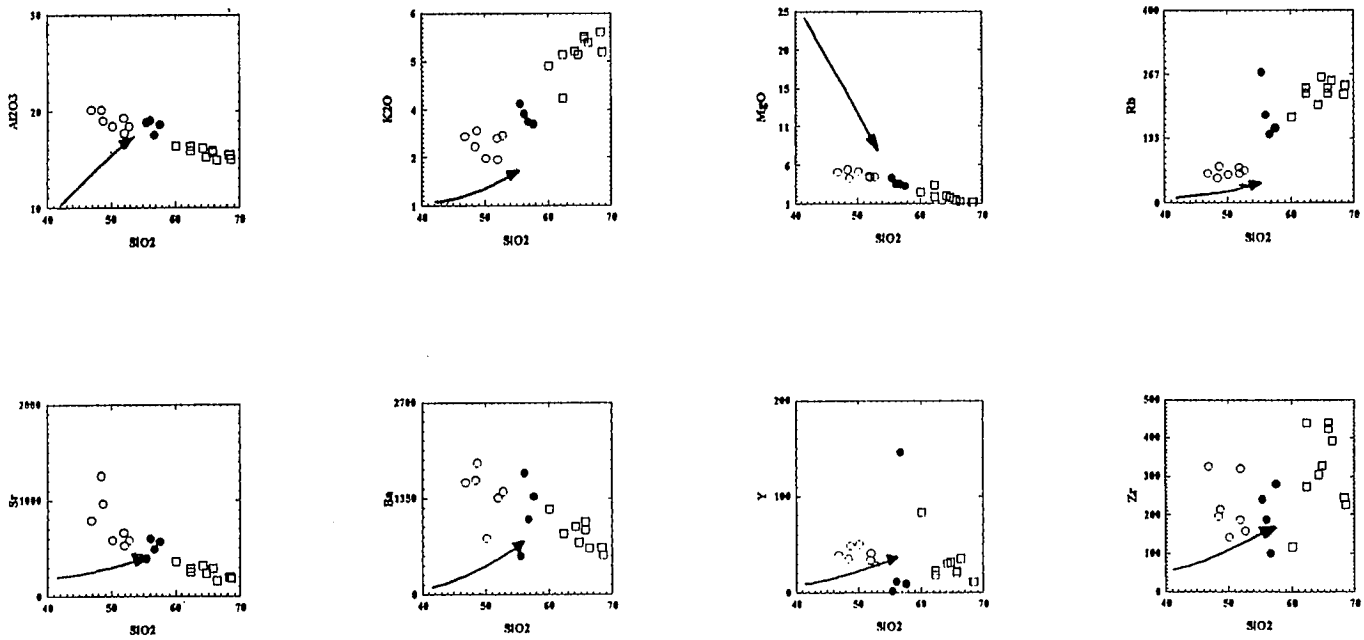

Fig. 1.- Variation diagrams of SiO_2 vs. selected major and trace elements for the Toledo gabbros (circles), Argés type quartz-diotites - tonalites (dots), and Argés type granodiorites and granites (squares). The trend of La Bastida gabbros is also shown. Fields in the K_2O vs. SiO_2 diagram are according to Rickwood (1989).

Fig. 1.- Diagramas de variación con SiO_2 como índice de diferenciación de los gabros de Toledo (círculos), cuarzodioritas - tonalitas de tipo Argés (puntos gruesos) y granodioritas y granitos de tipo Argés (cuadrados). Se muestra también la pauta de los gabros de tipo La Bastida. Campos en el diagrama SiO_2 - K_2O según Rickwood (1989).

al., (1990)) are essentially unrelated from a genetic point of view. Second, mixing between the magmas which gave rise to the gabbros and Argés granites is most unlikely to have occurred mainly because of the absence of any petrographical features, mixing lines and the difficulty of reconciling the REE data with such a process. Third, the intermediate-acid Argés group seems to be related by a crystal fractionation mechanism to a theoretical parental magma of intermediate composition. This mechanism agrees with the major, trace and REE data of these rocks (e. g. the positive Eu anomaly found in several intermediate varieties of the Argés group).

The present work presents preliminary Sr-Nd isotopic data for La Bastida and Toledo gabbros and some new data for the Argés association and argues for the aforementioned conclusions in the light of the new isotopic data.

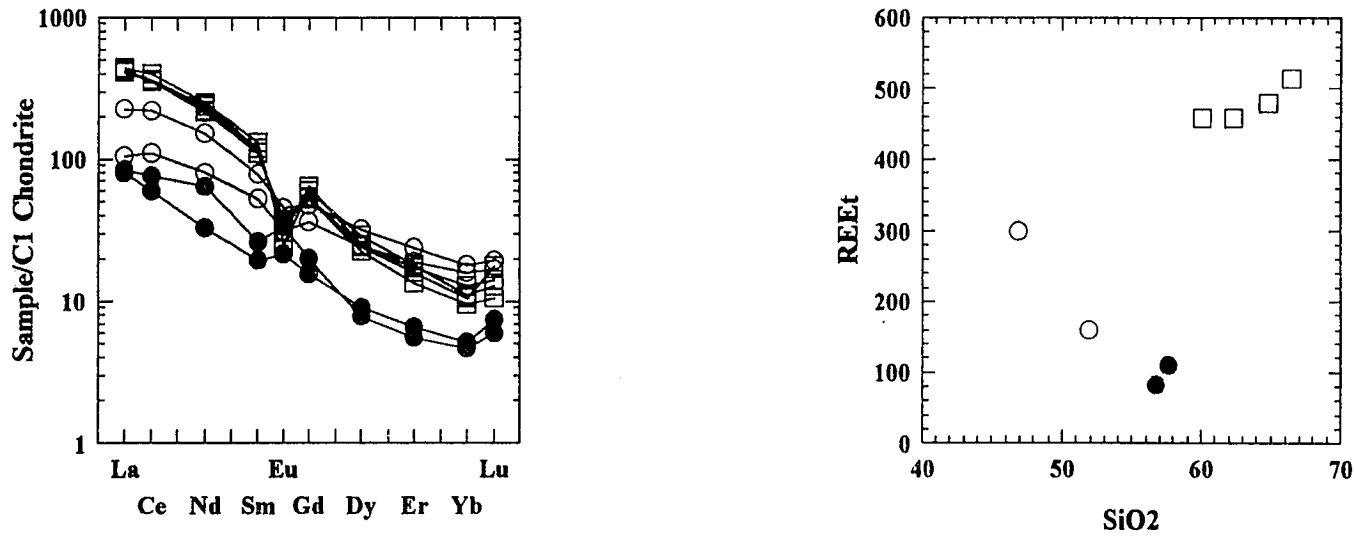

Fig. 2.- A) Chondrite normalized REE patterns for the Toledo gabbros, Argés quartz-diorites - tonalites and Argés granodiorites and granites. B) Total REE vs. SiO_2 variation diagram. Symbols as in figure 1.

Fig. 2.- A) Espectros de TR de los gabros de Toledo, cuarzodioritas tonalitas de tipo Argés y granodioritas y granitos de Argés. B) Diagrama de variación del contenido total en TR frente a sílice. Símbolos como en la figura 1.

Summary of the geochemical features

A full set of chemical data for these rocks can be found in Barbero (1992a, b) and Barbero *et al.*, (1990).

The two gabbroic series considered here present clearly different evolutionary trends. La Bastida gabbros define a calc-alkaline trend which is slightly richer in FeO_t and TiO_2 compared to most calc-alkaline series. La Bastida gabbros evolve from olivine gabbros with a high MgO (Fig.1), Cr and Ni content to olivine-free terms; there is a compositional gap and a change in the slope of the evolutionary trend between both types exists. A crystal fractionation process with olivine and plagioclase as cumulus phases in the most basic types satisfactorily explains the geochemical features of this series (Barbero, 1992).

Toledo type gabbros show very contrasted geochemical characteristics when compared with La Bastida types. They vary from slightly silica undersaturated gabbros (normative Ne ranges from 5.5 to 0.7) to silica saturated quartz-gabbros. They have many of the geochemical features which are typical of the shoshonitic association (Morrison, 1980): (1) They are close to silica saturation; (2) There is no Fe-enrichment trend on the AFM diagram; (3) They show total alkalis contents higher than 5% wt; (4) K_2O/Na_2O ratios are higher than 0.6 for silica contents of around 50% wt; (5) They are enriched in P, Sr, Ba, HFSE (specially Zr, Y, Nb) and LREE; (6) Al_2O_3 contents are high. Their high Ti, Zr and P contents result in plotting in the alkaline field in the Winchester and Floyd (1976) diagram. An important chemical feature of this series is the increase in Cr content with increasing silica, which agrees with the observed higher modal abundance of clinopyoxene in the most acid varieties. Also some HFSE seem to decrease with increasing silica content. The chemical features that give rise to the shoshonitic affinity of this series could be related to crustal contamination as discussed later in the text.

Finally, the Argés granitic series varies from quartz-dioritic and tonalitic rocks to granodiorites and monzogranites. They define a calc-alkaline trend in an AFM projection and in the R1-R2 diagram (La Roche *et al.*, 1980). Variation trends are linear for MgO and CaO and slightly curved for P_2O_5, Al_2O_3, TiO_2 and Sr. On Harker variation diagrams the Argés trends are in continuity with those of the Toledo gabbros for most of the elements with the exception of the REE (Figs. 1 and 2). The intermediate varieties of the Argés series show lower total REE contents than both the acid types of the

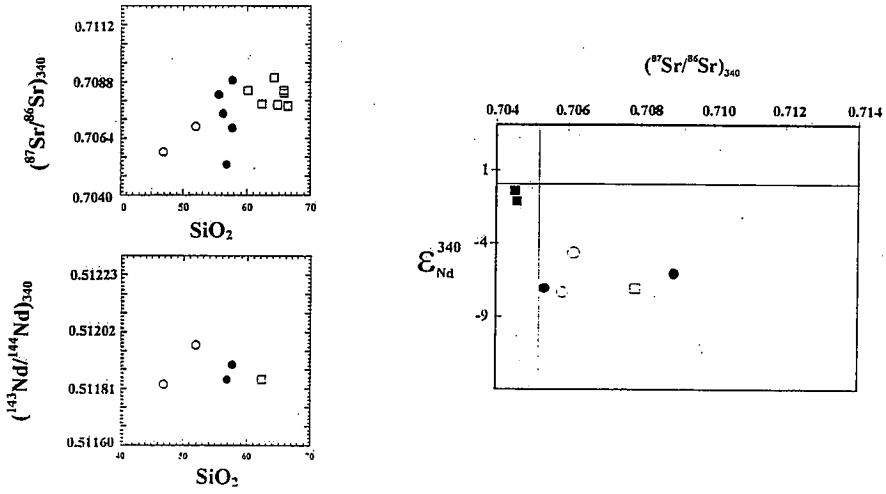

Fig. 3.- Initial Sr ratios (340 Ma) (A) and e_{Nd} values (B) vs. SiO_2 diagrams which illustrate the considerable isotopic heterogeneity shown by these rocks. C) Initial Sr vs. e^i_{Nd} diagram. La Bastida gabbros are also plotted. See text for further explanation. Symbols as in fig. 1.

Fig. 3.- A y B) Diagramas de relaciones iniciales a 340 Ma de Sr y e^i_{Nd} frente a sílice en los que es posible observar la gran heterogeneidad isotópica de las rocas estudiadas. C) Diagrama de la relación inicial de Sr frente a e^i_{Nd}. Ver texto para mayor explicación. Símbolos como en la figura.1.

Argés series and the Toledo gabbros. This seems to be difficult to reconcile with a genetic relationship between both groups and also with any hypothesis involving mixing of a basic magma represented by the Toledo gabbros and an acid one represented by the Argés granodiorites or monzogranites in order to generate the intermediate varieties of both series.

Sr-Nd isotopes. Analytical methods

Seven samples have been selected for isotopic analysis. Two of them correspond to La Bastida gabbros; two are Toledo gabbros; two are tonalitic varieties of the Argés series; and one is a granodiorite of the Argés series. In one of the tonalitic varieties garnet and monazite have been separated following standard methods and analysed for Sr-Nd isotopes. The rest of the Sr isotopic data of the Argés series is taken from Andonaegui (1990). Sr and Nd isotopic determinations were performed at SURRC using techniques described in Barbero et al. (1995). Sr isotopic ratios were corrected for mass fractionation using $^{87}Sr/^{88}Sr = 0.1194$. During the course of this study the NBS987 Sr standard gave $^{87}Sr/^{86}Sr = 0.71023 \pm 4$ (2 s. d.). $^{143}Nd/^{144}Nd$ ratios were normalised to $^{146}Nd/^{144}Nd = 0.7219$. A Johnson and Matthey Nd standard gave $^{143}Nd/^{144}Nd = 0.511500 \pm 10$ (2 s. d.). Rb and Sr contents were determined by isotope dilution techniques, the Rb being analysed on a VG Micromass 30 mass spectrometer. Sm and Nd were determined by ICP-AES techniques at CNRS (Nancy, France). The 2 s. d. error on ε_{Nd} values is $\pm$ 0.4.

Results

As shown in figure 3, the two samples of La Bastida gabbros (an olivine-bearing type and an olivine-free one) have the highest e^i_{Nd} and the lowest $(^{87}Sr/^{86}Sr)_i$ ratios of the rock types studied. Such values are similar to other basic rocks from the Hercynian Central Iberian Zone (e. g. Moreno-Ventas *et al.*, 1995), and suggets a greater contribution from mantle-derived melts than in the other types from the ACT. This is also consistent with the high Mg numbers and high Cr and Ni contents found in these rocks which are the only gabbroic rocks found in this part of the Central Hercynian area (Sierra de Guadarrama and Montes de Toledo) with clear mantle signatures.

The Toledo type gabbros show several noteworthy features: First, their low e^i_{Nd} values do not suggest a solely mantle derivation for the gabbroic magmas; and secondly, they are strongly heterogenous in terms of ε^i_{Nd}. Moreover, although the data are very scarce, the most silica rich sample presents the less negative ε^i_{Nd} value, indicating a more primitive character. This behaviour of Nd isotopes contrasts with the initial Sr isotopic signature that indicates a more mantle-like character for the more basic rock.

Finally, as observed in Figure 3, the Argés granitic series have low ε^{i}_{Nd} values broadly similar to those of the Toledo gabbros. The data also reveal a strong heterogeneity both in terms of Sr and Nd isotopes. Nevertheless, there is a difference of 1.1 epsilon units between one of the tonalite samples and the other two samples analysed. This heterogeneity precludes the use of whole-rock Rb-Sr and Sm-Nd geochronology in these rocks as was partially envisaged by Andonaegui (1990). This isotope heterogeneity is present even on a hand specimen scale as revealed by data from mineral separates from a sample of tonalitic composition (Barbero *et al.*, 1995).

Petrogenetic constraints

From a petrographical and geochemical point of view it is apparent that La Bastida gabbros are genetically unconnected to the other gabbroic series of the area, and also from the calc-alkaline Argés granitic series. Their initial Sr and Nd isotopic signatures suggests that they contain a greater proportion of mantle-derived material than either the Toledo gabbros or the Argés granitic series. They are thus probably more closely related to an increased thermal input from mantle to the ACT.

The origin of the Toledo type gabbros is not so clear. The shoshonitic affinity of this series does not seem to be a primary feature, and was more likely produced by some kind of crustal contamination process or hydrothermal interaction with magmatic (?) fluids related to the spatially and temporally associated Argés series. It is not clear if a crustal contaminant can explain the high Sr and Ba content of the Toledo gabbros. At the moment, any of the metamorphic rocks of the ACT, in the case they were the contaminants, can explain the high Sr and Ba of the Toledo gabbros. The Toledo gabbros are almost exclusively found as enclaves, mega-enclaves or small massifs within the Argés type granites, and so the possibility of they having been interaction between both liquids (the gabbroic and the granitic) and a fluid phase has to be considered. Hydrothermal fluids carrying LILE such as Ba, K, and also LREE, Sr, Zr, Nb, Y, etc. could be responsible for the overall trace-element enrichment observed in the gabbros and in some tonalitic varieties of the Argés series. This seems to be in agreement with the interstitial and oikocrystalline textures of the hydrous minerals found in the Toledo gabbros, and also with the possibility of the amphibole being of secondary origin replacing clinopyroxene as suggested by petrographical observations (Barbero, 1992). As these gabbros precede the metamorphic climax of the area, most of their primary features are partially obliterated making the investigation of their origin a difficult task.

The conclusions reached by Barbero et al. (1990) with respect the genetic relationships between the basic rocks and the Argés granites are not contradicted by the isotopic results. Nevertheless, several questions arise from the new isotopic data. Firstly, what is the origin of the isotopic heterogeneity shown by both, the Toledo gabbros and the Argés type tonalites?. Second, if, as seems likely from the petrographic, major and trace element data, the Toledo gabbros and the Argés series are genetically unrelated, what processes make some of them isotopically similar and yet so different from the rest of the samples of their respective suites (fig. 3)?. In this respect it is important to consider the possibility of local-scale interaction with hydrothermal fluids which could change the isotopic signature. Future investigations on stable isotopes and additional chemical and Sr and Nd isotopic data are needed in order to understand the origin of this basic-acid association.

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