

Sr-Nd isotopic heterogeneities in high-grade metamorphic conditions: an example from the anatectic complex of Toledo (Spain)

Heterogeneidades isotópicas Sr-Nd en condiciones de alto grado metamórfico: el ejemplo del Complejo Anatéctico de Toledo (España)

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ABSTRACT

Preliminary data on the study of Sr-Nd isotopes in metapelitic, restite-rich granitoids and anatectic leucogranites from the Anatectic Complex of Toledo (Centro-Iberian Hercynian zone), reveal the absence of isotopic homogenization as it would be expected in a high grade metamorphic area in which important volumes of anatectic leucogranites are generated. Several factors as the short-lived metamorphic climax, the highly anhydrous conditions, and the source heterogeneity seem to be crucial for isotopic homogenization to be not achieved.

RESUMEN

Los primeros datos del estudio de los isótopos de Sr y Nd en materiales metapelíticos, granitoides ricos en restitas y leucogranitos anatócticos del Complejo Anatóctico de Toledo (zona Centro Ibérica Hercínica), revelan la ausencia de homogenización isotópica, como cabría esperar en un área que ha sufrido un metamorfismo de alta temperatura acompañado de generación de importantes volúmenes de granitoides anatócticos. Factores como la corta duración del clímax metamórfico, las condiciones anhidras del área y la heterogeneidad de las fuentes parecen ser fundamentales para que el metamorfismo de alta temperatura y la fusión no lleguen a producir esta homogenización, como suele ocurrir en la mayoría de las ocasiones.

Key words: isotopic resetting, Hercynian Iberian Belt.

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Introduction

It is generally accepted that metamorphism causes considerably mobility on a small scale of the chemical constituents of rocks, either due to the presence of a fluid phase and/or by diffusion of ions. Consequently, metamorphism may produce a pronounced change in parent/daughter elemental ratios. In the case of high temperature metamorphism accompanied by crustal anatexis, radiogenic isotopes contained within mineral phases are redistributed and the geochronological and geochemical information may be significantly affected. If a particular mineral is totally consumed or if diffusion is rapid enough to allow equilibration, all the pre-anatexis information contained in the mineral is lost (Faure, 1986; Chernyak & Ryerson, 1993).

There are several well documented examples of whole rock isotopic (Sr-

Nd) homogenization achieved in high temperature scenarios, in which melting is usually produced. Peucat (1986) in the St Malo Massif describes Sr isotope homogenization in anatectic granites, whereas the associated metatextitic and diatextitic gneisses remain highly heterogeneous. Bickle *et al.*, (1988) describe homogenization of $^{87}\text{Sr}/^{86}\text{Sr}$ and $^{18}\text{O}/^{16}\text{O}$ within large volumes of crust during Hercynian regional metamorphism and crustal anatexis in the Trois Seigneurs Massif; the range of Sr isotopes heterogeneity that they describe is between 0.713 to 0.717 in the high-grade pelitic schists. In an adjacent area to the ACT, in the Anatectic Complex of Peña Negra (Sierra de Gredos), Pereira *et al.*, (1992) describe Sr isotope homogenization in materials that are in part similar to those in the ACT.

From these studies it seems unlikely that isotopic homogenization (± 0.002 in $^{87}\text{Sr}/^{86}\text{Sr}$) is achieved unless high

grade metamorphic conditions are long-lived and fluids are present (Fiorentini *et al.*, 1990).

The purpose of this paper is to present the preliminary Sr-Nd isotopic data from the high grade metamorphic rocks and anatectic peraluminous granitoids of the ACT, which indicate a profound isotopic heterogeneity at the regional, and possibly local scales. The importance of several factors leading to this heterogeneity is also discussed.

Geological setting

The ACT has been thoroughly described by Barbero (1992) and references therein. It is mainly composed of high-grade metamorphic rocks, the most abundant types being granulitic migmatites of pelitic composition, and augen orthogneisses, with minor amounts of marbles, semipelitic gneisses, amphibolites, conglomerates and calc-silicate

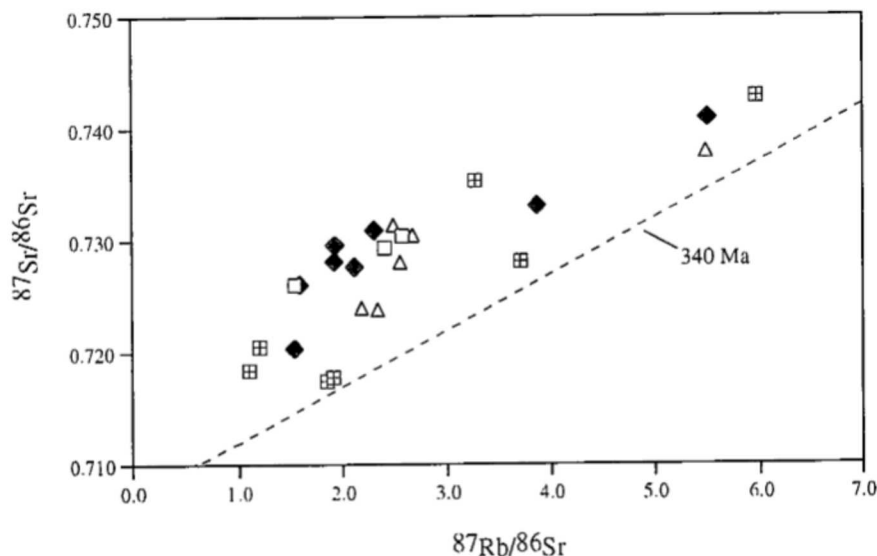


Fig. 1.- $^{87}\text{Rb}/^{86}\text{Sr}$ vs. $^{87}\text{Sr}/^{86}\text{Sr}$ diagrams in which it is clear the absence of an isochron relationship in the metapelites and anatectic leucogranites of the ACT, indicating the absence of a regional-scale Sr isotopic homogenization. A 340Ma reference line is drawn. Legend as follows: full diamonds=metapelites, triangles=Layos granite, open squares=leucosomes, crossed squares=Cervatos granites.

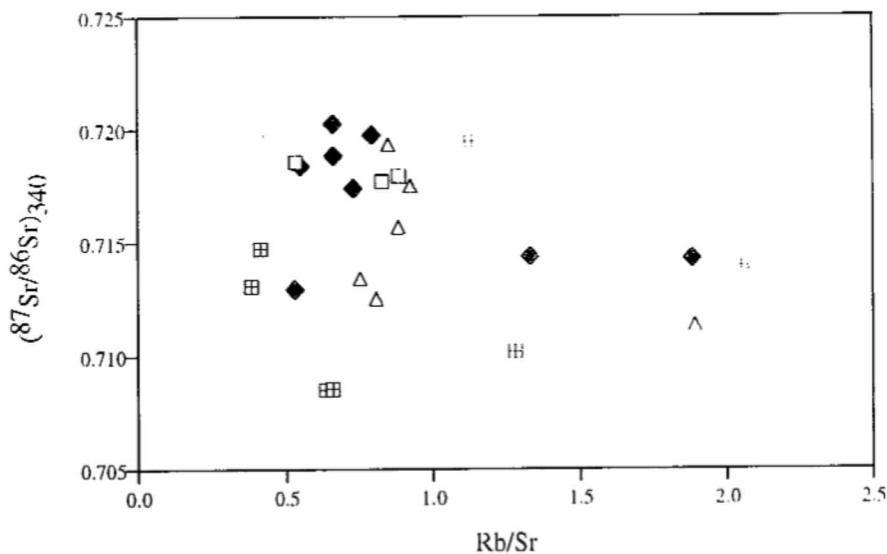


Fig. 2.- $(^{87}\text{Sr}/^{86}\text{Sr})_{340}$ vs. Rb/Sr showing the profound heterogeneity at the possible metamorphic climax age. Note that this heterogeneity occur also within the individual lithologic groups. Same legend as in fig. 1

rocks. There is also a varied suite of Hercynian granitoid rocks, some of them predate the metamorphic climax (the Argés granites and associated basic rocks), but the most abundant types are anatectic granitoid s. l. generated during the metamorphic climax of the area. Within this group the main petrographic types are restite-rich melagranitoids (Layos granite) and garnet/cordierite-bearing leucogranites (Cervatos leucogranites) (Barbero, 1992; Barbero & Villaseca, 1992). The estimated meta-

morphic conditions for this area are 800-850°C, 4-6 kb, and aH₂O around 0.4, thus representing strongly water-undersaturated granulite facies conditions (Barbero, 1992; Barbero, in press). Radiometric ages for these rocks are scarce; there are only two Rb-Sr errorchrons made in the Argés granites which give values of 318 and 372 Ma (Andonaegui, 1990). In this work we use a reference age of 340 Ma in the calculation of the initial ratios which is probably close to the age of the metamorp-

hic climax of the area. Nevertheless, variations of up to 50 Ma do not invalidate the conclusions of the present work. Geochronological data in order to estimate the age of the granitoids, the thermal peak and subsequent cooling are been performed, but results are not already available (Barbero *et al.* in prep.).

Analytical Methods

20 representative samples have been collected for chemical and isotopic analysis. Six of them correspond to metapelites; ten are different varieties of leucogranites and leucosomes (three); four correspond to restite-rich granites. One Sr data for the Layos granite and four for the Cervatos leucogranites are taken from Andonaegui (1990).

Sr and Nd isotopic determinations were performed in the Scottish Universities Research and Reactor Centre, East Kilbride, Scotland. Rb and Sr were separated using standard cation techniques. Analyses were made in a VG Isomass 54E single collector mass spectrometer. Sr isotope ratios were corrected for mass fractionation using $^{86}\text{Sr}/^{88}\text{Sr}=0.1194$. Rb and Sr were determined by isotopic dilution. Sm and Nd were separated by standard anion exchange column techniques. Analyses were made on a VG SECTOR 54-30 multicollector mass spectrometer. $^{143}\text{Nd}/^{144}\text{Nd}$ ratios were normalized to $^{146}\text{Nd}/^{144}\text{Nd} = 0.7219$. Sm and Nd were determined by ICP-AES techniques at CNRS (Nancy, France). Six Sm-Nd determinations were also made by isotope dilution techniques obtaining results in total agreement with the ICP data.

Results and discussion

When the data on these rocks are plotted on a $^{87}\text{Rb}/^{86}\text{Sr}$ vs. $^{87}\text{Sr}/^{86}\text{Sr}$ diagram (fig. 1) it is apparent that an isochron cannot be defined, and so large-scale Sr-isotope homogenization probably did not occur during the metamorphic climax of the area, unless later events have disturbed in such a way to disguise any previous isochron relationship. When the initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratios at 340 Ma are calculated (fig. 2) the existence of a significant heterogeneity is evident, not only when comparing different lithologies but when considering them individually. Thus, the metapelitic rocks have $(^{87}\text{Sr}/^{86}\text{Sr})_{340}$ which vary from 0.714 to 0.720; the Layos granites from 0.712 to 0.720 and the Cervatos leucogranites

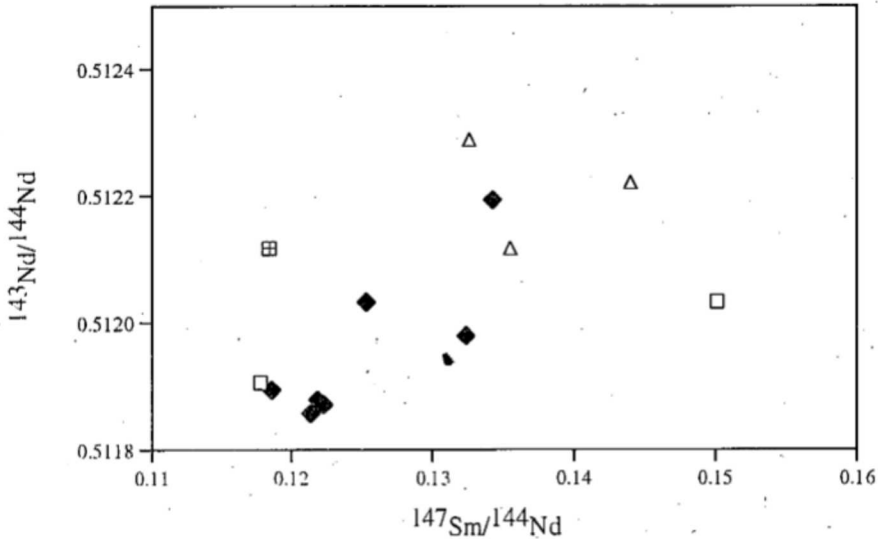


Fig. 3.- $^{147}\text{Sm}/^{144}\text{Nd}$ vs. $^{143}\text{Nd}/^{144}\text{Nd}$ diagram showing the absence of isochron relationship and thus of Nd regional homogenization in the considered materials. Same legend as in fig. 1.

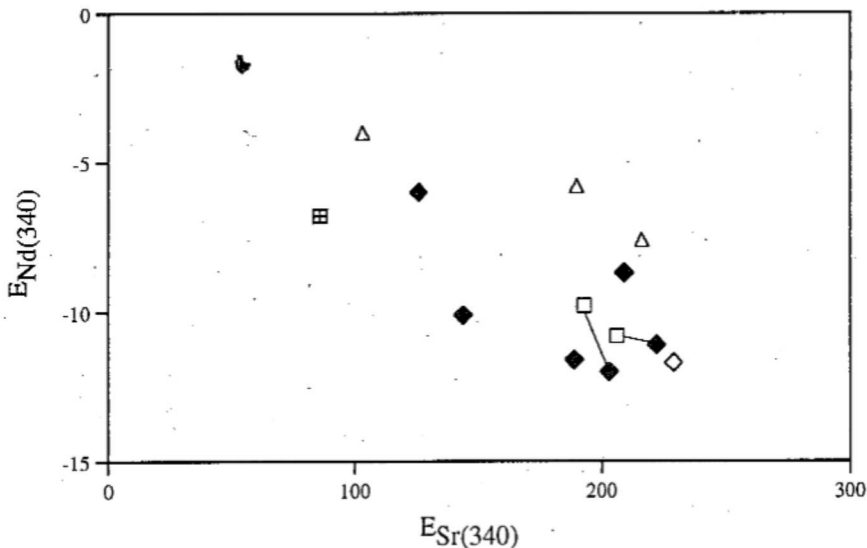


Fig. 4.- $\epsilon_{\text{Nd}}(340)$ Ma vs. $\epsilon_{\text{Sr}}(340)$ Ma diagram summarizing the variation of the initial Sr and Nd isotope ratios. Tie-lines connect mesosome-leucosome pairs. Same legend as in fig. 1.

from 0.711 to 0.720. Although the Nd isotopic data are more scarce, the available results also indicate a major isotopic heterogeneity (fig. 3). Again no isochron relationship is observed indicating a lack of regional scale homogenization of the Sm-Nd system. $^{143}\text{Nd}/^{144}\text{Nd}$ ratios at 340 Ma in the metapelitic rocks vary from 0.51147 to 0.51189; in the Layos granites from 0.51153 to 0.51171; and in the leucogranites from 0.51138 to 0.51160 (fig. 4).

These isotopic heterogeneities are not entirely surprising for the metapelitic rocks, as was previously noticed (Bickle *et al.*, 1988), but the degree of

heterogeneity is unexpected for the Layos and Cervatos type leucogranites, taking into consideration that melting can be an efficient process for producing isotopic homogenization (Hofmann & Kohler, 1973). It is difficult to assess the scale of this isotopic heterogeneity, mainly because neither a metre nor centimetre-scale sampling has not been made. Nevertheless, two of the analysed Cervatos leucogranites that belong to a single hectometric massif and were sampled within a few meters, show a marked difference in $(^{87}\text{Sr}/^{86}\text{Sr})_{340}$ Ma ratios which seems to indicate that the heterogeneity can be profound even at a

metre scale. In the same way, three pairs of mesosome-leucosomes from the migmatitic granulites were sampled. On figure 4 these pairs are connected by a tie-line and it is evident that no Sr and Nd homogenization has occurred during the generation of this migmatites at a centimetre scale.

Three main factors control the isotopic homogenization in anatectic scenarios:

1.-*The heterogeneity of the source.* For large degrees of melting an homogeneous source is likely to produce an isotopically homogeneous melt. In the absence of significant magma chamber convective processes, a melt derived from a heterogeneous source is more likely to contain initial isotopic heterogeneities.

2.-*The melting process.* In the majority of the plutons, isotopic homogenization may occur as a result of melting, but this is not necessarily the general case, especially in restite-rich systems. In particular, if one or more of the phases of the protholith remain as a restite, they will maintain their isotopic signature whereas the melt will have an isotopic signature derived from the other phases that participate in the process. Nevertheless, it is possible that restite would equilibrate with the melt, which is mainly dependent on: -the closure temperature of the different isotopes in the different phases; - the grain size of the restitic minerals; - the cooling rate. Following the experimental results of Gilletti (1991), Cherniak & Watson (1992), and Cherniak & Ryerson (1993), considering a relatively rapid cooling rate between $10^\circ\text{C}/\text{Km}$ and $100^\circ\text{C}/\text{Km}$ and a regional peak temperature of 800°C , anorthite could be closed to exchange of Sr at grain sizes larger than $5 \cdot 10^{-2}$ cm in diameter; orthoclase and apatite at size larger than $5 \cdot 10^{-1}$ cm. The closure temperature for Sm is around 100°C higher and so is more likely to retain information about the source (Cherniak & Ryerson, 1993). So, large grains are more likely to be closed to isotopic exchange. If isotopic homogenization occurs mainly as a result of diffusion, which is also strongly temperature dependent, the longer the thermal climax, the more likely is homogenization to be achieved. The lack of isotopic homogenization during the melting and high T metamorphism of the ACT could indicate that the thermal peak in the ACT was short-lived and the cooling from the peak conditions after decom-

pression was quite rapid. Such scenario is also suggested by the presence of small-scale chemical disequilibrium in metapelitic and granitic rocks of the ACT, as such the differences in Fe/Mg ratios found in different textural types of cordierites, which are not expected in such a high temperature environment (Barbero, 1994, in press).

Finally, the presence of a fluid phase could also be an important factor as more rapid diffusion is clearly favoured under hydrated conditions. a_{H_2O} estimated for the ACT is around 0.4 (Barbero, 1994, in press), and such anhydrous conditions suggest that the diffusion would be seriously restricted and that isotopic homogenization may be limited.

3.- *The magma dynamics.* The low melting rate, the high restite content, the undersaturated water conditions, and the silica-rich composition of these granites, together with the absence of important magmatic storage and the high

viscosity of the melts seriously prevent the physical processes leading to isotopic re-homogeneization (convection, mixing...).

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