

Anatectic granites of the Sierras Pampeanas from Córdoba (Argentina): U-Pb SHRIMP and zircon trace element LA-ICP-MS study of diachronic metamorphism and crystallization

Granitos anatócticos de las Sierras Pampeanas de Córdoba (Argentina): edades U-Pb SHRIMP y estudio LA-ICP-MS de elementos traza en circón de metamorfismo y cristalización diacrónicos

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ABSTRACT

In this contribution we present new U-Pb SHRIMP ages and in situ LA-ICP-MS trace element geochemistry of zircon crystals from the Río de los Sauces anatectic granite, Córdoba, Argentina. Notable difference in texture and composition allowed us to identify two zircon populations in a single granite sample that are interpreted as reflecting metamorphic and igneous origins. Zircons regarded as restitic crystals entrained during the melt segregation yielded a slightly older concordia age of 537.1 ± 4.8 Ma (2σ) than those interpreted as igneous, dated at 529 ± 6 (2σ) Ma. Inherited metamorphic zircons are interpreted to represent solid-state growth during high temperature metamorphism of the Pampean Orogeny at the onset of the anatexis or metamorphic peak. Meanwhile, igneous zircons would record the crystallization age of Zr within the Río de los Sauces granite. The textural, compositional and geochronological data of both zircon populations suggest that the inception of the anatexis, the melt segregation and crystallization occurred during a short period of time of 8 my.

Key-words: Pampean orogeny, Pampean metamorphism, Río de Los Sauces granite, U-Pb SHRIMP dating, LA-ICP-MS

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Introduction

The Sierras Pampeanas geological province, in central Argentina, comprises several mountain ranges constituted by an igneous and metamorphic basement that was mostly generated during two main orogenic events: the Pampean and the Famatinian orogenies (Casquet *et al.*, 2018; Rapela *et al.*, 2018; Weinberg *et al.*, 2018). The Pampean orogeny is widely represented in the Sierras de Córdoba (Fig. 1), the southernmost part of the Sierras Pampeanas geological province, in which the main tectono-thermal event led to an upper amphibolite to granulite facies metamorphism and anatexis (Rapela *et al.*, 1998; Guerreschi and Martino, 2014). Gneisses and schists evolved into meta-

texitis and diatexitis at P-T conditions that reached 8–9 kbar and more than 800 °C (Rapela *et al.*, 1998; Otamendi *et al.*, 2004; Weinberg *et al.*, 2018), generating melts that segregate to form granitic bodies. Available ages suggest that this HT metamorphic event has lasted for at least 35 Ma, between 550 and 515 Ma (Rapela *et al.*, 1998; Weinberg *et al.*, 2018). The studies addressing the peraluminous magmatism associated with this metamorphic event are concentrated in specific parts of the Sierras de Córdoba, and have dated magmatism at 522 Ma, synchronous with metamorphism and anatexis (Rapela *et al.*, 1998, 2002; Tibaldi *et al.*, 2008). However, anatexis and associated magmatism are not necessarily coeval and the time gap between them

RESUMEN

En este trabajo se aportan nuevos datos de edades U-Pb SHRIMP y análisis in situ LA-ICP-MS de elementos traza de circones provenientes del granito Río de los Sauces, Córdoba, Argentina. A partir de marcadas diferencias texturales y composicionales se pudieron identificar dos poblaciones de circones en una misma muestra del granito, las cuales sugieren orígenes metamórficos e ígneos. Las edades concordia obtenidas en los circones metamórficos e ígneos fueron de $537,1 \pm 4,8$ Ma (2σ) y 529 ± 6 (2σ) Ma, respectivamente. Se interpreta que los circones metamórficos representan el crecimiento en estado sólido durante el metamorfismo de alta temperatura de la orogenia Pampeana, durante el inicio o el clímax de la anatexis. Por su parte, las edades de los circones ígneos representan la edad de cristalización del granito Río de los Sauces. Los datos texturales, composicionales y geocronológicos de ambas poblaciones de circones sugieren que el inicio de la anatexis, la segregación del fundido y la cristalización ocurrieron durante un periodo breve de tiempo de 8 my.

Palabras clave: orogenia pampeana, metamorfismo pampeano, granito Río de Los Sauces, datación U-Pb SHRIMP, LA-ICP-MS

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may differ in each single case (Vanderhaeghe *et al.*, 1999; Keay *et al.*, 2001; Esteban *et al.*, 2015).

In this contribution we present LA-ICP-MS trace element data and U-Pb SHRIMP ages of zircon crystals sampled from a single site of the Río de los Sauces granite, Sierra de Comechingones (Argentina), in which both metamorphic and igneous events have been recorded. We report here for the first time in the Pampean orogeny the diachronic character of metamorphism and associated granitic magmatism.

The Río de los Sauces granite

The Río de los Sauces granite is a 1200 x 150 m tabular body located two kilome-

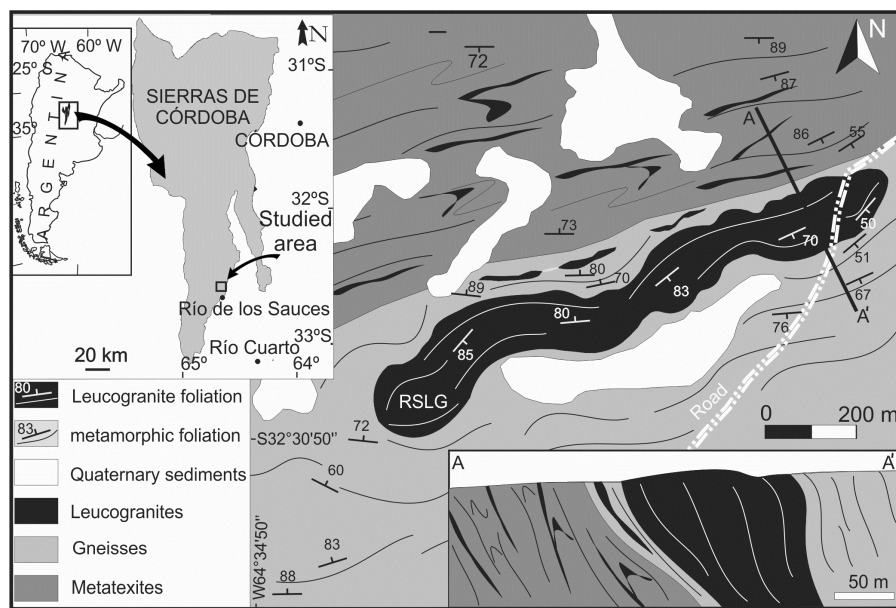


Fig. 1.- Geological map and cross-section of the sheet-shaped, Río de los Sauces granite. Inset shows its location in the Sierras de Córdoba, central Argentina.

Fig. 1.- Mapa y corte geológicos del granito Río de los Sauces, con morfología laminar. El recuadro en la esquina superior izquierda muestra la localización en las Sierras de Córdoba, centro de Argentina.

ters northwards from the Río de los Sauces village (Fig. 1). It intrudes garnet-rich gneisses and metatexites, the last ones showing stromatic structures. Leucosomes frequently coalesce and rise along axial-plane foliations forming sheet-shaped or even pluton-like pegmatite-leucogranite bodies.

The Río de los Sauces granite is one of these examples in which the coalescence of several leucogranite sheets led to the formation of a tabular-shaped pluton intruded concordantly with the foliation of the enclosing gneisses, close to the gneiss-metatexite contact (Fig. 1). A weakly foliated, coarse-grained leucogranite (microcline + quartz + plagioclase + biotite + muscovite + garnet ± sillimanite, and minor accessories, such as zircon, sphene and apatite) is the main igneous facies. Pegmatitic textures are distributed as small patches within the Río de los Sauces pluton.

U-Pb SHRIMP zircon ages

The main leucogranite facies of the Río de los Sauces pluton was sampled in only one station (32°30'37.7''S / 64°34'18.8''W). Zircon crystals were separated and mounted by conventional methods. Further imaging by cathodoluminescence and analyses on a SHRIMP-III/MC were performed at the Centro de Pesquisas Geocronológicas, University of São Paulo (CPGeo-IGC-USP; Brazil).

Two types of zircons were identified from CL images (Fig. 2): zircon population 1 and 2 (ZP₁ and ZP₂). The first one (ZP₁) is represented by complex zoned patterns, with dark rims at CL images surrounding inherited xenomorphic cores, dark luminescent idiomorphic zircons with weak oscillatory zoning and Th/U ratios lower than 0.02. Zircons from the second population (ZP₂) are prismatic and bipyramidal with concentric undisturbed oscillatory growth zoning.

Nine and eight spot analyses in zircon crystals from ZP₁ and ZP₂ yielded ²⁰⁶Pb/²³⁸U concordia ages of 537.1 ± 4.8 (2σ) (Fig. 3A) and 529 ± 6 (2σ) Ma (Fig. 3B), respectively. Although these two ages partially overlap each other, they could indicate that both zircon populations are not coeval.

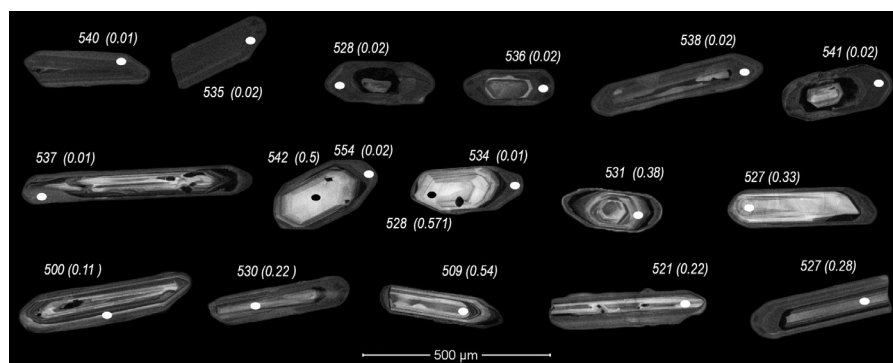


Fig. 2.- Cathodoluminescence images of the analyzed zircons from the Río de los Sauces granite. Labels indicate corresponding ²⁰⁶Pb/²³⁸U ages and Th/U ratios (in parentheses).

Fig. 2.- Imágenes de catodoluminiscencia de los circones analizados del granito Río de los Sauces. Los rótulos indican la correspondiente edad ²⁰⁶Pb/²³⁸U y la relación Th/U (entre paréntesis).

LA-ICP-MS geochemistry

Sixty-eight zircon crystals from both populations of the same sample, after SHRIMP acquisition, were analysed by Laser Ablation Quadrupole Inductively Coupled Plasma Mass Spectrometry (LA-Q-ICP-MS) at the University of the Basque Country to obtain trace and rare earth element (REE) concentrations.

As it was stated above, one of the most prominent geochemical differences is the Th/U ratio, being lower in the ZP₁ and higher in the ZP₂. This ratio has been used to discriminate between magmatic (Th/U > 0.1) and metamorphic (Th/U < 0.1) zircons (e.g., Hoskin and Schaltegger, 2003), although some discrepancies have been stated (Harley et al., 2007). In our study, the differences in Th/U ratios between both populations are even greater (Fig. 4A), suggesting clear contrasting origins (metamorphic vs. igneous).

Other geochemical ratio, such as Nb/Ta, also suggests differences in their origin, being almost invariably higher in ZP₂ when compared with ZP₁ (Fig. 4B).

Regarding the rare earth elements (REE), both zircon populations show positive patterns of normalized values with high overlap between them. Heavy REE contents, however, are somewhat different. For example, the (Lu/Dy)_N ratios are less variable in zircons from ZP₁ (1.3-2.4) than those from ZP₂ (0.8-3.6).

The release of U during dehydration reactions in partial melting processes leads to an increase in the U/Ce ratio of zircons with metamorphic origin (Castiñeiras et al., 2011). Zircons from the ZP₁ display U/Ce values that range between 21 and 936, whereas those from the ZP₂ vary only from 6-54 (Fig. 4C). The Ti-in-zircon geothermometer (Ferry and Wat-

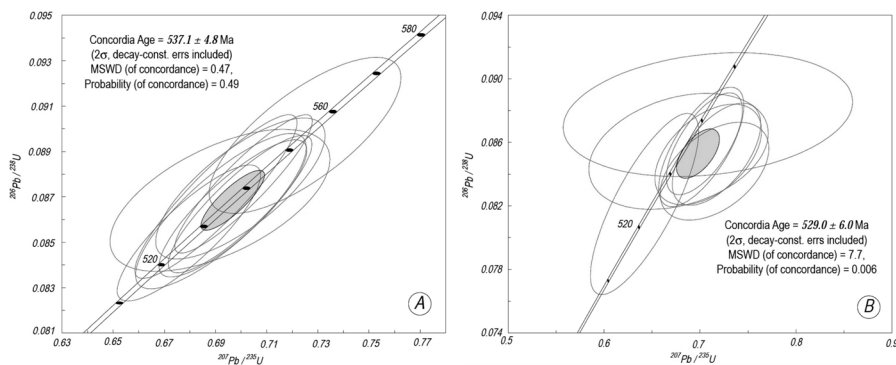


Fig. 3.- Conventional Concordia plots of (A) ZP₁ (metamorphic low Th/U zircons), (B) ZP₂ (igneous high Th/U zircons).

Fig. 3.- Gráficos de Concordia convencional de (A) la población de circones 1 (circones metamórficos con relaciones Th/U bajas), (B) la población de circones 2 (circones ígneos con relaciones Th/U altas).

son, 2007) was applied in this study, obtaining mean temperatures of 735 ± 17 and 750 ± 22 °C for the ZP₁ (4.5 ppm Ti) and ZP₂ (5.5 ppm Ti) zircons, respectively. Although temperatures obtained from both populations are similar within uncertainties, slightly higher values can be identified in zircons from ZP₂ with respect to ZP₁ (Fig. 4D).

Discussion

Textural and geochemical evidence were used to discriminate the two zircon populations of the Río de los Sauces granite. Zircons from the first population (ZP₁) have textural (zoned patterns, dark rims and inherited cores) and geochemical (low Th/U and Nb/Ta, and high U/Ce) features consistent with metamorphic origin. By contrast, long prismatic and bipyramidal crystals from the ZP₂, with significantly high Th/U and Nb/Ta and low U/Ce ratios, are here interpreted to be of igneous origin.

The above stated textural and geochemical differences among both zircon types are consistent with the U-Pb SHRIMP ages since the metamorphic zircons from ZP₁ are ~8 ma older than igneous zircons from ZP₂, as it can be observed from concordia ages.

According to field relationships, textural and geochemical evidence, the age of 529 Ma obtained in zircons from ZP₂ is here interpreted as the crystallization age of the Río de los Sauces granite. Field relationships, *i.e.*, the intrusion of the sheet-like Río de los Sauces pluton into gneisses after leucosome coalescence, also point to the emplacement and crystallization of this igneous body during the waning of the HT metamorphic event of the Pampean orogeny in

the Sierras de Córdoba. Therefore, the age of 537.1 Ma obtained in dark CL rims of metamorphic zircons from ZP₁ are deemed to represent the age of the HT Pampean metamorphism. This metamorphic event might be the responsible for the solid-state growth of the zircon rims. The zircon crystals would have been further transported within the anatectic magma until it was emplaced and crystallized at 529 Ma. The obtained ages in both zircon populations are

strongly correlated with other ages reported by several authors for the Pampean metamorphism and magmatism in the Sierras de Córdoba (Guereschi and Martino, 2014; and references therein). The results here presented imply that crystallization of melt segregations after partial melting of metasedimentary rocks took place around 8 ma later than the HT regional metamorphism.

A time lag between syntectonic granites and regional metamorphism was previously reported by some authors in other orogenic domains. Keay *et al.* (2001), for example, proposed that Miocene peak metamorphism and related magmatism in the Naxos Island, Greece, were separated more than 5 ma each other. Esteban *et al.* (2015) also established a time span of 7 ma between the metamorphic climax of the high-grade Variscan HT/LP metamorphism (Late Carboniferous) and the final emplacement of the Lys-Caillouas pluton at middle crustal levels.

The presence of metamorphic zircons in the Río de los Sauces granite suggests that zircon crystals derived from the metamorphic protoliths have

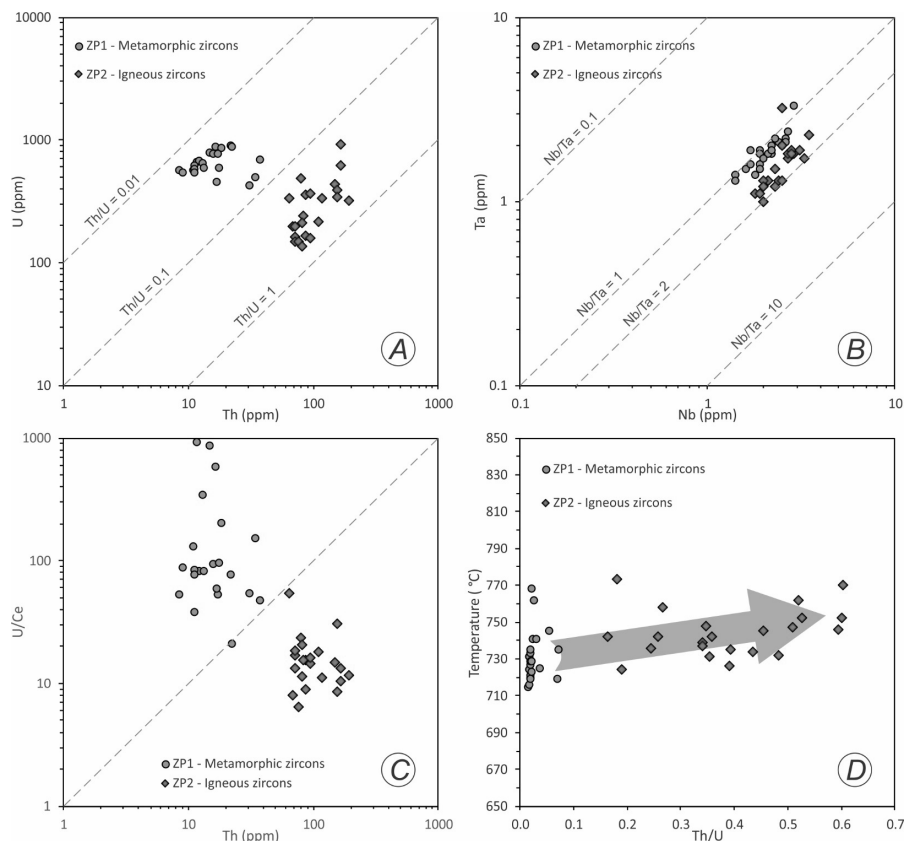


Fig. 4.- Bivariate diagrams of both zircon populations (metamorphic-ZP₁ and igneous-ZP₂): (A) Th vs. U; (B) Nb vs. Ta; (C) U/Ce vs. Th; (D) Th/U vs. temperature. See color figure in the web.

Fig. 4.- Diagramas bivalentes en ambas poblaciones de circones (metamórficas ZP1 e ígneas ZP2): (A) Th vs. U; (B) Nb vs. Ta; (C) U/Ce vs. Th; (D) Th/U vs. temperatura. Ver figura en color en la web.

been incompletely dissolved and then included as restitic crystals thus allowing to study the timing of the metamorphism prior to the emplacement of the pluton. The mean temperatures of 735 and 750 °C in metamorphic and igneous zircons respectively are coherent with calculated metamorphic conditions in Sierras de Córdoba (Rapela *et al.*, 1998; Otamendi *et al.*, 2004). Since the crystallization temperatures calculated for both zircon populations are within the uncertainty of each other, a further increase in the regional temperature during anatexis cannot be inferred.

Conclusions

The anatectic Río de los Sauces granite represents the coalescence, expelling, emplacement and crystallization of leucosomes from the surrounding migmatites. Zircons analyzed from a single sample of the Río de los Sauces pluton were grouped into two populations whose textural, compositional and geochronological features point to a contrasting origin: near peak high-temperature metamorphic solid-state growth vs. magma crystallization. These two events were separated in time by ~8 ma (537.1 vs. 529 Ma). Our contribution is the first constraint of this time lag for the Pampean orogeny in the Sierras de Córdoba.

Acknowledgments

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