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Zircon crystal morphology and internal structures as a tool for constraining magma sources: Examples from northern Portugal Variscan biotite-rich granite plutons

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ABSTRACT

In northern Portugal, large volumes of granitoids were emplaced during the last stage (D_3) of the Variscan orogeny and display a wide range of petrological signatures. We studied the morphologies and internal structures of zircons from syn-, late- and post-D_3 granitoids. The sin-D_3 granitoids include the Ucanha–Vilar, Lamego, Felgueiras, Sameiro, and Refoios do Lima plutons, the late- and post-D_3 granitoids are represented by the Vieira do Minho and the Vila Pouca de Aguiar plutons, respectively. Typological investigations after Pupin (1980) along with scanning electron microprobe imaging reveal that the external morphology of zircon changes consistently with a decrease in the crystallization temperature. Zircon populations from the Refoios do Lima and the Vieira do Minho granites show gradual changes in the internal morphologies and their typologic evolution trends are consistent with their mainly crustal origin. The Sameiro, Felgueiras, Lamego and Ucanha-Vilar granites have more complex internal and external morphology and typological evolution trends that cross the domain of the calc-alkaline to the aluminous granites compatible with a mixing process. Finally, the morphological types of the Vila Pouca de Aguiar granites are found both in calc-alkaline and sub-alkaline granites and their typological evolutionary trends follow the calc-alkaline/sub-alkaline trend, suggesting crustal sources with some mantle contribution.

1. Introduction

Zircon is an important accessory mineral of granitic rocks, very resistant to weathering and metamorphic processes. The different zircon crystal morphologies that characterize different kinds of granites depend on magma chemistry, changes in the temperature of crystallization and aluminium-alkali balance (Pupin, 1976; Pupin and Turco, 1972, 1975); therefore, zircon populations have been used as tracers of granitic magma petrogenesis. Among several morphological parameters, the crystal habit is the most variable and carry important petrogenetic information, as pointed out by Pupin and Turco (1972, 1975) and Pupin (1976, 1980, 1985, 1988). However, the principles of Pupin's method were challenged by several authors (e.g., Benisek and Finger, 1993; Vavra, 1990, 1993) stating that zircon crystal morphologies could only reflect the latest stages of granitoid evolution. According to Vavra (1990, 1993), the external morphology of a single crystal can change a number of times during a single growth event

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as a result of kinetic factors, such as diffusion rates and adsorption, which affect the growth rates of the crystal faces and therefore control the morphology of a growing crystal. The influence on the growth rate of different forms can be attributed to either the degree of zircon saturation or the incorporation of trace elements (Vavra, 1994). On the other hand, Benisek and Finger (1993) have shown that a relative development of the zircon prisms faces is strongly related with zircon-supersaturation of the melt, instead of the crystallization temperature.

With the present morphological zircon study, we aimed to characterize the source reservoirs involved in the generation of sin-, late- and post-D_3 biotite-rich granitoids from northern Portugal, a suite of geochemically well-characterized plutons, which have been the subject of intensive whole-rock and mineral-scale studies (Almeida et al., 2002; Dias et al., 1998, 2002; Martins et al., 2007, 2009, 2013; Simões, 2000) testing the classic "Pupin method" against the petrogenetic indications given by geochemical and isotopic data.

2. Geological setting

The central and western Iberian Peninsula constitutes a segment of the West European Variscan Fold Belt, the Iberian Massif. Tectonic characteristics of the European Variscides are those of a classical subduction–collision–obduction model – in this case, the collision of the Laurentia and the Gondwana continents, with minor intermediate blocks. The geological evolution of this segment has been described in detail by several authors (Bard et al., 1980; Dias and Ribeiro, 1995; Lagarde et al., 1992; Matte, 1991; Ribeiro et al., 1983, 1990). Three main ductile deformation phases, D1, D2 and D3, are identified in the NW Iberian Massif, responsible for the structural development of this part of the Variscan belt (Dias and Ribeiro, 1995; Noronha et al., 1979). The last phase, D4, is related to an extension regime, post-collision, with brittle deformation. During the last ductile deformation phase (D3) of the Variscan orogeny, large volumes of granitoids were emplaced in northern Portugal. This was the main period of successive generation of granites (Ferreira et al., 1987), which exhibit large compositional variability (Dias et al., 1998; Martins et al., 2009, 2013). The classification of granitoids is related to this third phase of deformation (Dias et al., 1998; Ferreira et al., 1987; Martins et al., 2009, 2011, 2013) divided into:

- syn-D_3 granitoids, 313–319 Ma (peraluminous biotite granodiorites to monzogranites and highly peraluminous two-mica leucogranites);
- late-D3 biotite-dominant granitoids, 306–311 Ma (mainly as composite massifs displaying a wide compositional range from gabbroic to granitic, being metaluminous to peraluminous);
- late- to post-D3 granitoids, ca. 300 Ma (highly peraluminous, two-mica leucogranites);
- post-D3 granitoids, 290–296 Ma (slightly metaluminous to peraluminous monzogranites occurring as zoned plutons).

Syn- and late-D3 biotite-rich granodiorites and monzogranites are the most abundant granitic rocks in northern Portugal, spatially associated with mafic microgranular enclaves and minor bodies of basic to intermediate rocks.

3. Geology and petrological signatures

The granitic plutons selected for this study are located in the central Iberian Zone, northern Portugal. They are syn-D_3 biotite granitoids, late-D_3 biotite-dominant granitoids and post-D_3 biotite granitoids (Fig. 1) whose emplacement was controlled by important tectonic regional structures like ductile shear zones or Late Variscan fragile fracturing and faulting.

3.1. *Syn-D_3 biotite granitoids*

This group is spatially related to the Vigo–Régua shear zone, and includes, from south to north, the Ucanha–Vilar, Lamego, Felgueiras, Sameiro and Refoios do Lima plutons.

They are porphyritic (orthoclase phenocrysts) medium-grained biotite granodiorites/monzogranites and contain quartz + plagioclase (andesine/oligoclase) + perthitic orthoclase + biotite + zircon + monazite + apatite + ilmenite ± muscovite ± allanite (+ cordierite + sillimanite in the Refoio do Lima pluton) (Dias et al., 2002; Simões, 2000). The Ucanha–Vilar is spatially associated with hm-sized granodioritic stocks. Mafic microgranular enclaves are common, although they are rare, in the Refoios do Lima pluton. The U–Pb zircon geochronological data for Ucanha–Vilar, Lamego, Sameiro and Refoios do Lima granites have given crystallization ages between 313 and 321 Ma, with almost concordant monazite ages of 317 and 318 Ma.

They are interpreted as moderately peraluminous with magnesian and alkali-calcic affinity (Frost et al., 2001), being the Refoios do Lima the most aluminous. SiO_2 contents range from 62 to 70% and are characterized by rather high Ba (720–2181 ppm), high LREE contents (La = 77–167 ppm), highly fractionated patterns (La_N/Yb_N = 32–78) and moderate negative Eu anomalies (Eu/Eu^* = 0.52–0.72). On the other hand, these granitoids display $^{87}Sr/^{86}Sr$ initial ratios and ε_{Nd} values varying in the ranges 0.7072–0.7116 and –4.4 to–6.3, respectively (Dias et al., 2002; Simões, 2000).

3.2. *Late-D3 biotite-dominant granitoids*

Late-D_3 biotite-dominant granitoids are represented by the Vieira do Minho pluton. This pluton is composite and consists of two different granite units (Almeida et al., 2002; Martins et al., 2013): the Vieira do Minho granite (VM) is a coarse-grained monzogranite and the Moreira de Rei (MR) granite a medium-grained monzogranite.

The two granites are porphyritic and present the following mineral association: quartz + perthitic K-feldspar (orthoclase or microcline) + plagioclase (oligoclase-andesine) + biotite ± muscovite. Andalusite and cordierite were also observed, but only in one sample from the Vieira do Minho granite. Apatite, zircon, titanite, ilmenite, monazite