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Geochemical and isotopic constraints on the petrogenesis of Early Ordovician granodiorite and Variscan two-mica granites from the Gouveia area, central Portugal

A.M.R. Neiva [a,*], I.S. Williams [b], J.M.F. Ramos [c], M.E.P. Gomes [d], M.M.V.G. Silva [a], I.M.H.R. Antunes [e]

[a] Department of Earth Sciences, University of Coimbra, 3000-272 Coimbra, Portugal
[b] Research School of Earth Sciences, The Australian National University, Canberra, ACT, 0200, Australia
[c] INETI, Apartado 1089, 4466-956 S. Mamede de Infesta, Portugal
[d] Department of Geology, University of Trás-os-Montes e Alto Douro, 5000-911 Vila Real, Portugal
[e] Polytechnic Institute of Castelo Branco, 6000-919 Castelo Branco, Portugal

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ABSTRACT

A biotite granodiorite and seven Sn-bearing two-mica granites crop out in the Gouveia area, central Portugal. A SHRIMP U–Th–Pb zircon age from the granodiorite, and monazite ages from four of the two-mica granites, show that they are of Early Ordovician (~480 Ma) and Permo-Carboniferous, i.e. Variscan (~305 and 290 Ma) age respectively. The Variscan two-mica granites are late- and post-D3. Major and trace element variation in the granitic rocks and their biotite and muscovite indicate mainly individual fractionation trends. The granitic rocks are mostly depleted in HREE relative to LREE. The biotite granodiorite is probably derived from igneous lower crust, as evidenced by low initial $^{87}Sr/^{86}Sr$ (0.7036), high εNd_T (+2.5) and moderate $\delta^{18}O$ (8.8‰). The two-mica granites are probably derived by partial melting of heterogeneous mid-crustal metasediments, mainly metapelite and some metagraywacke, as evidenced by their high initial $^{87}Sr/^{86}Sr$ (0.7076–0.7174), $\delta^{18}O$ (10.7–13.4‰) and major element compositions. However, variation diagrams for major and trace elements from two of the muscovite>biotite granites and their micas define fractionation trends. Rb–Sr whole-rock analyses from the two granites are perfectly fitted to a single isochron and the rocks have sub-parallel REE patterns; the younger granite is derived from the older by fractional crystallization of quartz, plagioclase, biotite and ilmenite (tested by modelling major and trace elements). Most of the Sn-bearing granites are derived from distinct magma batches. They result from partial melting of a heterogeneous mid-crustal metasediment. They do not represent a crustal anomaly in tin. Fractional crystallization is responsible for the increase in the Sn contents of the granites and their micas. Muscovite has a higher Sn content than coexisting biotite and is the principal host mineral for Sn in these rocks.

1. Introduction

The Gouveia area lies within the Central Iberian Zone, which is the innermost zone of the Iberian Massif. This massif corresponds to the south-western extension of the European Variscan Belt. Large volumes of granitic rocks were emplaced in the region, mainly during the third Variscan deformation D3 from 320 to 300 Ma (Dias et al., 2002), which generated multiple subvertical strike-slip shear zones (Valle Aguado et al., 2005). At lower crustal levels, the high temperatures possibly resulted from high thermal gradients from D2 and syntectonic granitoid intrusions. At higher crustal levels D3 occurred under greenschist facies retrograde conditions (e.g. Abalos et al., 2002). Many of the Variscan granitoids are significantly enriched in Sn. Some early plutonic rocks in the Central Iberian Zone, with ages between 500 and 455 Ma, predate the Variscan orogeny (Zeck et al, 2007).

Unaltered Sn-bearing granites commonly contain 18–26 ppm Sn (Lehmann, 1990), four to five times more Sn than ordinary granites (3–5 ppm Sn, e.g. Lehmann, 1987; Solomon et al., 1994). Fractionation of S-type magmas increases their Sn contents (Lehmann, 1982; Neiva, 1984; Lehmann, 1990; Sawka et al., 1990; Blevin and Chappell, 1995; Neiva, 2002; Gomes and Neiva, 2002). In general, primary Sn and W deposits are derived from hydrothermal systems related to Sn-bearing granites. Igneous cassiterite occurs only locally in a few granites (Haapala, 1997; Gomes and Neiva, 2002).

The granitic rocks from the Gouveia area range from granodiorite to granite. Some Variscan granites are cut by Sn-bearing granitic aplite–pegmatite dykes and veins (Neiva et al., 2008), so it is important to characterize the parent granites and explain their Sn enrichment. This paper presents the geology, petrography, mineralogy, geochemistry and isotopic (Rb–Sr, Sm–Nd, $\delta^{18}O$, U–Th–Pb) characteristics of the granitic rocks from the Gouveia area. Our aim was to date the emplacement of the granitic rocks, and to understand the mechanisms responsible for their origins, evolution and Sn enrichment. One outcome

* Corresponding author. Tel.: +351 239 860500; fax: +351 239 860501.
E-mail address: neiva@dct.uc.pt (A.M.R. Neiva).

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of our work was the discovery of an undeformed Early Ordovician granodiorite, a rarity in Portugal.

2. Geology

Granitic rocks, intruded into a Cambrian schist–metagraywacke complex, predominate in the Gouveia area (Fig. 1). Seven different Variscan two-mica granitoids have been identified (G2–G8), and also an Early Ordovician medium- to coarse-grained slightly porphyritic biotite granodiorite (G1) that crops out in the south around Manteigas. Three of the Variscan granitoids are late-D3; medium- to fine-grained porphyritic muscovite > biotite granite G2, medium-grained slightly porphyritic muscovite > biotite granite G3 and coarse- to very coarse-grained porphyritic biotite > muscovite granite G4. Four of the Variscan granitoids are post-D3; coarse-grained porphyritic muscovite > biotite granodiorite to granite G5, medium- to coarse-grained slightly porphyritic muscovite > biotite granite G6, medium-grained muscovite > biotite granite G7 and fine- to medium-grained slightly porphyritic biotite ≈ muscovite granite G8.

The Early Ordovician granodiorite has a hornfels contact metamorphic aureole. The Variscan granitoids mostly produced a contact metamorphic mica schist, but locally there is an inner zone of pelitic hornfels surrounded by mica schist. Most of the contacts between the granitic rocks are sharp (Table 1), but the granodiorite to granite G5 locally grades into granite G6. In general, the granites contain xenoliths of metasedimentary origin and rarely microgranular enclaves (Table 1).

The schist–metagraywacke complex and granitic rocks are cut by subvertical aplite and pegmatite veins and NE–SW, NNE–SSW and locally subvertical N–S and NW–SE trending quartz veins containing cassiterite and wolframite. The schist–metagraywacke complex and granites G4, G5, G6 and G8 are also cut by subhorizontal, mainly NW–SE and NE–SW trending, Sn-bearing aplite–pegmatite dykes and veins. NE–SW and NNE–SSW trending faults cut the rocks and quartz veins.

3. Petrography

According to the classification of Le Maitre et al. (2003), most of the granitic rocks are granites *sensu stricto*. G1 and one sample of G5 are granodiorites. All the granitic rocks have a subhedral granular texture and most of them contain feldspar phenocrysts (Table 1). Some show the effects of deformation; quartz and feldspar have undulose extinction, micas are bent and quartz is fractured. Biotite granodiorite G1and the two-mica granites contain quartz, microperthitic microcline, plagioclase and biotite, but the latter also contain muscovite (Table 1).

Quartz contains inclusions of the minerals belonging to the mineral assemblage of the granite. Plagioclase and microcline compositions are given in Table 1. Commonly biotite and muscovite are intergrown and host inclusions of zircon, apatite and ilmenite, but also of magnetite in biotite granodiorite G1, and of monazite in the two-mica granites. The micas in G1, G2, G3 and G4 show some preferred orientation. However, it decreases from G2 to G4 and is less marked in G1.

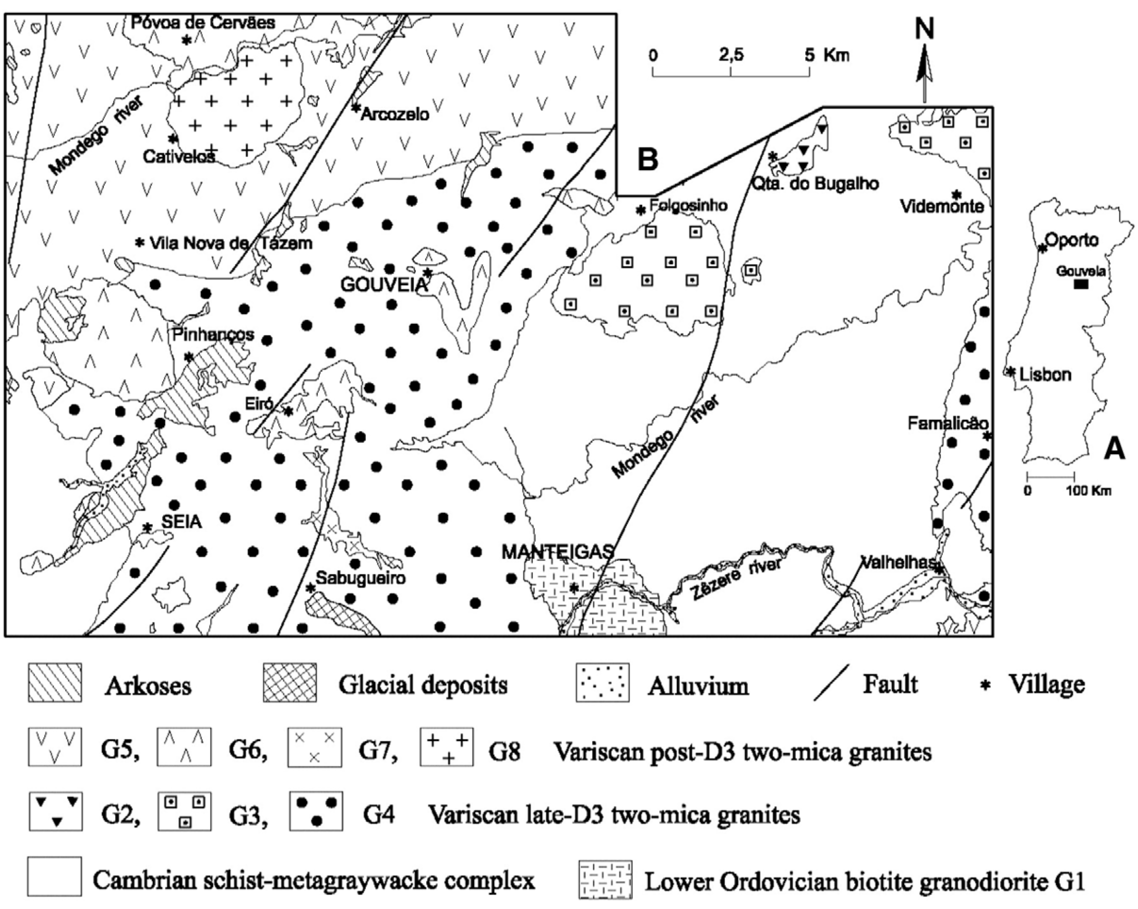

Fig. 1. A. Location of the study area in Portugal. B. Geological map of the Gouveia area. G1—medium- to coarse-grained slightly porphyritic biotite granodiorite; G2—medium- to fine-grained porphyritic muscovite > biotite granite; G3—medium-grained slightly porphyritic muscovite > biotite granite; G4—coarse- to very coarse-grained porphyritic biotite > muscovite granite; G5—coarse-grained porphyritic muscovite > biotite granodiorite to granite; G6—medium- to coarse-grained slightly porphyritic muscovite > biotite granite; G7—medium-grained muscovite > biotite granite; G8—fine- to medium-grained slightly porphyritic biotite ≈ muscovite granite.