Journal of South American Earth Sciences 68 (2016) 187–204

Contents lists available at ScienceDirect

Journal of South American Earth Sciences

journal homepage: www.elsevier.com/locate/jsames

Geochemical and isotopic evidence for the petrogenesis and emplacement tectonics of the Serra dos Órgãos batholith in the Ribeira belt, Rio de Janeiro, Brazil

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ARTICLE INFO

Article history:
Received 1 July 2015
Received in revised form
10 January 2016
Accepted 11 January 2016
Available online 13 January 2016

Keywords:
Ribeira belt
Serra dos Órgãos Batholith
Petrogenesis
Tectonic

ABSTRACT

The Serra dos Órgãos batholith in the State of Rio de Janeiro (Brazil) is a NE-SW-trending elongated body that occupies *ca.* 5000 km^2 in plan view. It is a foliated intrusion, especially at its borders and is crosscut by syn-magmatic shear zones, with foliations that are moderately-to steeply-dipping to the northwest and moderately-to shallow-dipping in the center and to the southeast, in a configuration of a large laccolith. It was emplaced between 560 and 570 Ma, during an extensional episode that was part of a series of events that comprise the Brasiliano Orogeny in SE Brazil, and which includes deformation, metamorphism and granite intrusion during the interval between 630 and 480 Ma. The two main rock types in the batholith are biotite-hornblende monzogranite, and biotite leucogranite, with subordinate tonalite, granodiorite, diorite, quartz diorite (enclaves), aplite and pegmatite. Harker-type diagrams help show two rock groups with similar trends of evolution: a dioritic and a granitic. The first one is tholeiitic, whereas the second is calc-alkaline, with medium-to high-K calc-alkaline affinity and metaluminous to slightly peraluminous character. In both groups strong decrease in Al_2O_3, MgO, FeOT and CaO relative to silica contents are observed, which is compatible with trends of fractional crystallization involving clinopyroxene and/or hornblende, plagioclase, opaque minerals, apatite, microcline and biotite. The Sr and Nd isotopic data suggest recycling of a Paleoproterozoic crust as an important petrological process to generate the batholith rocks. Geothermometry (amphibole composition) and geobarometry (saturation in zircon and apatite) indicate that most of the batholith solidified at mid to lower crustal levels at about 750 °C and between 5 and 5.5 kbar. We consider that Serra dos Órgãos crustal protoliths underwent melting caused by the interaction with hotter mafic magma at the base of the crust. These two magmas, with distinct initial compositions and rheology, probably underwent mixing and mingling. This process continued during the rise of the magma through the crust, which was accompanied by magmatic differentiation. The main feature that characterizes the post-collisional Serra dos Órgãos granite magmatism is the connection with high angle ductile shear zones of continental scale and presence to a greater or lesser extent of mafic magmas.

1. Introduction

The Neoproterozoic/Cambrian granitic magmatism in the central part of the Ribeira belt was developed during an orogenic system newer in Southeastern Brazil, named Rio Doce Orogeny and best characterized in the Serra do Mar microplate, which represents the accretionary event that was active between 590 and 480 Ma (Campos Neto and Figueiredo, 1995). The authors separated this event into three tectonic stages: (i) pre-collisional (590–570 Ma), syn-collisional (560–530 Ma) and post-collisional (520–480 Ma). Further works, supported by geological mapping, tectonic analysis, geochemistry date and new geochronological and isotopic data, have characterized oldest magmatic arcs and described as Andean-

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http://dx.doi.org/10.1016/j.jsames.2016.01.005
0895-9811/

type These arcs are referred to as Rio Paraíba do Sul - ≥ 620/600 Ma (Machado and Demange, 1998; Machado et al., 2000), Rio Negro - 640–600 Ma (Tupinambá, 1999; Tupinambá et al., 2000) or 790–620/610/590 (Heilbron and Machado, 2003; Tupinambá et al., 2007, 2012; Heilbron et al., 2004) and Serra da Bolívia – 650–590 Ma (Heilbron et al., 2013).

The generation of large granitic batholiths is associated primarily with magmatic arcs related to active subduction environments or collisional environments linked to high-grade metamorphism. In Neoproterozoic orogenic belts that occur in Brazil, the main magmatism presents a post-collisional nature, with the syn-collisional granite having a very subordinate volume. The post-collisional granite magmatism have common characteristics were their connection with ductile shear zones of continental scale and presence to a greater or lesser extent of mafic magmas. These magmas, generally dioritic composition, underwent a physical and chemical mixing process with granitic magmas, generating hybridization structures at high temperatures and physical structural relationships based on crystallization conditions.

The Serra dos Órgãos batholith, the subject of this article, crops out in the central hill ranges of the Rio de Janeiro State. It is the largest batholith, forming a tabular body about 165 km long and 30 km wide, concordant with the tectonic regional structure. Here we present a review of previous work on the Neoproterozoic tectonic evolution of the region, on the granitoids of Rio de Janeiro, and on the Serra do Órgãos batholith. There follows a brief description of samples present in the batholith, together with a presentation of new geochemical data on whole rocks and minerals.

We discuss implications for the petrogenesis of the batholith, its tectonic environment and intrusion depth, based in detailed petrographic observations, structural data, and new isotopic (Sr and Nd), geochemical and geothermobarometric data.

2. Materials and methods

In the present study, approximately sixty samples from 3 traverses of the batholith were studied. Analyses of these samples were obtained on an Philips PW 1404 X-ray fluorescence spectrometer, or on Jobin JY-38Pi and JY32P atomic emission ICP spectrometers at the geochemical laboratory of the Saint Etienne School of Mines, France, after appropriate sample preparation. Chemical classifications of the rocks using the TAS (Le Bas et al., 1986) and the R1-R2 of La Roche et al. (1980) schemes (not shown) are usually in good agreement with the semi-quantitative modal classification. In cases where a major discrepancy between petrographic and chemical classifications was found (e.g. monzogranite versus tonalite, or quartz diorite versus granodiorite) priority was given to the petrographically assigned name.

Strontium isotope analyses of six rock samples were performed at the Geochemistry Laboratory of Clermont-Ferrand University, and two rock samples were analysed for neodymium isotopes in the Geochronology Laboratory of Rennes University, France. In both cases the same rock samples were used for analyses and they were selected based on previously obtained petrographic and geochemical data.

Other data geochronological were obtained by U/Pb method in multi-crystal zircon fractions, Pb/Pb in mono-crystal zircon by evaporation and Rb/Sr whole rock isochron (Cordani et al., 1973; Machado et al., 1996; Porto et al., 1996; Machado, 1997; Tupinambá, 1999). More recently, one sample of batholith was dated by U/Pb SHRIMP method yielding an age of 569 ± 6 Ma (Silva et al., 2003).

3. Tectonic context

3.1. The Ribeira belt

The Ribeira belt (Almeida et al., 1973) is part of the central segment of the Mantiqueira Province and extends for more than 1400 km along the southeastern coast of Brazil (Fig. 1), which is continuous along the strike of belt, with NE structural trend between the states of Paraná and Rio de Janeiro that changes to NS between the Espírito Santo and Minas Gerais (Almeida et al., 1981; Hasui and Oliveira, 1984; Trouw et al., 2000; Heilbron et al., 2004). The NE-SW to NNE-SSW oriented Ribeira belt has neoproterozoic ages and was developed by amalgamation of the São Francisco and Congo cratons and involved a complex history of collision and accretion/collage of terranes, microcontinents and island arcs (Campos Neto and Figueiredo, 1995; Brito Neves et al., 1999; Trouw et al., 2000; Heilbron et al., 2000, 2004, 2013, 2015; Heilbron and Machado, 2003; Silva et al., 2003).

Two orogenic systems are described by Campos Neto and Figueiredo (1995) in the central and northern segments of the Ribeira belt: an older, orogeny named 'Brasiliano I', which was of the collision type or controlled by ocean plate subduction, and occurred between 700 and 600 Ma; and another, younger, the Rio Doce Orogeny, with batholithic calc-alkaline plutonism indicating northwestern subduction, best characterized in the Serra do Mar Microplate by a magmatic arc, active between 590 and 570 Ma, with collisional stage between 560 and 530 Ma. In the final stage of the "Brasiliano I′ orogeny in the Apiaí-Guaxupé Microplate, occurred an alkali-calcic plutonism at 610 Ma that graded to rapakivi-like Fe-Hastingsite-biotite granites genesis with 600–580 Ma, marking the post-orogenic phase of this orogeny, which is synchronous with the establishment of a new magmatic arc. According to Hasui (2010), the collisional processes began in the Brasiliano I (900–700 Ma), but were mainly developed during the Brasiliano II (670–530 Ma) and ended in the Brasiliano III (580–490 Ma), resulting the orogenic systems Mantiqueira and Tocantins.

Pioneer studies (Rosier, 1957, 1965) suggested the presence of Alpine-style nappes in the Rio de Janeiro region. Subsequent studies have attempted to related the geological features to the tectonic evolution of destructive plate margins. (e.g. Demange et al., 1991; Wiedemann, 1993; Figueiredo and Campos Neto, 1993; Campos Neto and Figueiredo, 1995; Trouw et al., 2000; Tupinambá et al., 2012; Heilbron et al., 2000, 2004, 2013, 2015; Heilbron and Machado, 2003).

The Rio Paraiba do Sul positive flower structure associated with ductile shear zones of high angle corresponds to the main structural framework of the core of the Ribeira belt in Rio de Janeiro (Machado and Endo, 1993; Dehler et al., 2006). This structure, recognized since the 1960s, consists of oppositely dipping foliations to NW in its southern limb, and to SE in northwestern limb, and was initially described as fan-like structure (Ebert, 1968).

The Ribeira belt (RB) involves to the Serra do Mar microplate and Paraíba do Sul and Juiz de Fora terranes (Campos Neto and Figueiredo, 1995). The Serra do Mar microplates that consists of three middle-high grade metamorphosed terranes – *granulite-granite-migmatite*, *gneiss-migmatite* and *supracrustal* – has been accreted the Paraiba do Sul and Juiz de Fora terranes during the Cambrian collisional event of this sector of Gondwana (Campos Neto and Figueiredo, 1995). According to such authors, in the Búzios region, located in the eastern portion of the RB in Rio de Janeiro, there occurs an exotic terrane, known as the Cabo Frio terrane, composed of a paragneiss-quartzite sequence and high grade metamorphic ortogneisses of the Ryacian (2.2–2.0 Ga), that was affected by a tectono-metamorphic event that occurred in the