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U–Pb geochronology of the granite magmatism in the Embu Terrane: Implications for the evolution of the Central Ribeira Belt, SE Brazil

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ABSTRACT

The Embu Domain represents the central part of the Ribeira Fold Belt in São Paulo, Brazil. It hosts several granitic occurrences of varied composition ranging from small granitic bodies that outcrop in a domain bounded by the intersection of two major sutures (Taxaquara and Guararema Faults) and batholitic masses outcropping to the east. Understanding the evolution of such granites is of vital importance to better constrain evolutionary models for the Ribeira Belt. In the present study, a set of samples from eleven main granite occurrences from the east of São Paulo state was selected for geochronological investigation using laser ablation-multicollector-inductively coupled plasma spectrometry (LA-MC-ICP-MS) and thermal ionization mass spectrometry (TIMS) U–Pb dating of zircon and monazite crystals, respectively. The results indicate a remarkable cluster of ages around 590 Ma with older events of granite magmatism between 660 and 600 Ma registered for four plutons, indicating a long history of crustal reworking and magma generation.

The ages of reworked sources were evaluated from inherited zircon cores. Although highly discordant these point to the predominance of Paleoproterozoic (2.4–2.1 Ga) sources, with minor contributions from Mesoproterozoic (1.1–0.9 Ga) and Archean sources (~3.1 Ga). The new data bring important insights into the role played by the Embu Domain on the paleogeography and evolution of the Ribeira Belt.

1. Introduction

Granite magmatism is widespread in all sectors of the Neoproterozoic Mantiqueira Province in eastern Brazil. Studies on a regional scale have demonstrated that it consists of several distinct associations marking successive events of convergent (continental arc; collision) and extensional tectonism (Campos Neto and Figueiredo, 1995; Heilbron et al., 2008; Pedrosa-Soares et al., 2001). The Ribeira Belt corresponds to the central portion of the Mantiqueira Province (Heilbron et al., 2004) and is composed of several different domains/terranes, amalgamated during the convergence between the São Francisco and Southern Congo cratons; all these terranes were intruded by large volumes of Neoproterozoic granites spanning a wide age interval of at least 150 Ma (~650–500 Ma). Older manifestations with ages around 800 Ma have been reported in the Ribeira Belt (Cordani et al., 2002; Heilbron and Machado, 2003; Vlach, 2001) and appear to be related to an early convergent episode of arc magmatism and orogenesis, but these ages are scattered and were obtained on samples from poorly known occurrences of orthogneisses. A recent review by Heilbron et al. (2008) identifies in the central Ribeira Belt a major episode of granite generation related to the building of a continental margin magmatic arc at 635–620 Ma (Rio Negro Complex) followed by three main collision episodes, associated with metamorphism and granite generation. These collision events would be related to the west-vergent (towards the São Francisco craton) docking of the Embu and Paraíba do Sul terranes at 605–580 Ma, followed by docking of the Oriental terrane (at 580–550 Ma, corresponding to the Rio Doce orogeny of Campos Neto and Figueiredo, 1995) and finally by collision of the Cabo Frio terrane at 530–510 Ma.

In this model, the Embu Terrane corresponds to one of the first "exotic" masses accreted at 605–580 Ma to a continental mass just-formed (at ~630–610 Ma) by the amalgamation between the São Francisco and Paranapanema cratons (Campos Neto, 2000). Although voluminous, the granite magmatism of the Embu Terrane is still poorly known, and a systematic study of the main occurrences is necessary to fully understand the significance of this terrane and its connections with other portions of the Ribeira Belt. In a previous work (Janasi et al., 2003) that reported preliminary results of U–Pb TIMS monazite dating of peraluminous (mostly

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two-mica) leucogranites from the Embu Terrane, the results define a main age interval between 590 and 540 Ma. Even though peraluminous granites are notably abundant in the Embu Terrane, biotite granites, which often do not carry monazite, also constitute an important component of this magmatism. The present work focuses on U–Pb dating of representative granite plutons from the Embu Terrane making use mostly of "in situ" LA-MC-ICP-MS; some new TIMS dates of both zircon and monazite are also presented. These results complement previous dating and/or place constraints on the ages for some plutons previously investigated by TIMS (e.g., Janasi et al., 2003). The new geochronological results clearly document the age of main magmatic events of crustal melting and granite generation in the Embu Terrane. The application of high spatial resolution methodology also allows the investigation of provenance via the study of inherited zircon crystal cores within magmatic crystals.

2. Geological context

Fig. 1 is a sketch map of the main tectonic units of the crystalline basement of southeastern Brazil. The Mantiqueira Province runs NNE, roughly parallel to the coast, and is divided into three major segments, from north to south the Araçuaí, Ribeira and Dom Feliciano fold belts. It is therefore a tectonic feature developed after a previous event that amalgamated the São Francisco Craton with another cratonic mass now concealed below the Paraná Basin, and whose margins, strongly reworked by Neoproterozoic magmatism, are represented by the Apiaí-Guaxupé Terrane (Campos Neto, 2000).

The subdivision into the Araçuaí and Ribeira fold belts is in fact artificial, since they are contiguous, and the limit is arbitrarily set at the region in the north of the Rio de Janeiro State where the main direction of the tectonic structures change southwards from NNE to NE (Heilbron et al., 2008). However, correlations between these two belts are still controversial (e.g., Tupinambá et al., 2007). A major twofold division is recognized in the Ribeira belt:

(1) The western domain (Occidental Terrain of Heilbron et al., 2008), in tectonic contact with the cratonic area, exposes Neoproterozoic meta-supracrustal sequences and their Paleoproterozoic basement. Apparently, there is an important along-strike variation in depth of exposure, with progressively deeper levels appearing towards NE, where the medium-to high-grade Paraíba do Sul supracrustals occur as remnants among two older units (the Juiz de Fora granulites to the NW and the Quirino orthogneisses to the SE). Within the Embu Terrane, metasupracrustal rocks are largely predominant, and exposures of older rocks are scattered (Fig. 1); there is a clear predominance of lower-grade mica-schists towards SW, also consistent with exposure of shallower levels in this direction. Sm–Nd T(DM) ages of intrusive granites and metamorphic rocks are typically >1.8 Ga, reaching values up to 3.0 Ga. A metassedimentary sequence with ophiolitic remnants (Ribeirão da Folha Fm) and an association of calc-alkaline granitoids interpreted as representative of a magmatic arc formed by oceanic comnsumption (Galileia Batolith) separate the Juiz de Fora granulites from the São Francisco craton in the northernmost portion of this domain, already within the Araçuaí Fold Belt (Pedrosa-Soares et al., 2008).
(2) The eastern domain (Oriental Terrane of Heilbron et al., 2008) is dominated by high-grade metamorphic rocks intruded by huge volumes of foliated granitic rocks. No clear signs of basement are present, and the terrane is interpreted as a magmatic arc, initially developed in an oceanic setting and then at a continental margin, as evidenced by relatively high εNd(t) (+4 to −12, Heilbron et al., 2008) and lower Sm–Nd T(DM) (usually 1.4–1.6 Ga, but as low as 1.0 Ga).

The ~N60E trending Embu Terrane (Fig. 1 inset) is interpreted to have been laterally juxtaposed to the Apiaí-Guaxupé Domain by dextral escape tectonics concomitantly with a frontal collision further north between the Juiz de Fora Terrane and the São Francisco Craton (Campos Neto, 2000). Small basement inliers composed of migmatitic orthogneisses are exposed throughout the Embu Terrane (e.g., Fernandes, 1991), but metasupracrustal sequences affected by medium to high-grade metamorphism are predominant. The depositional age of these supracrustal sequences is poorly constrained, but is assumed by most authors to be Neoproterozoic; its upper limit is constrained by a widespread metamorphic event at ~800 Ma that was apparently coeval with early arc-related magmatism which produced calc-alkaline granites and tonalites now transformed into orthogneisses (Vlach, 2001; Cordani et al., 2002). There is no consensus in the literature about the internal divisions within the Embu Terrane, but there are suggestions that it may consist of a few blocks with more or less distinctive geological evolution. The Guararema Fault running N80E truncates the main structures of the Embu Terrane (Fig. 1) and metasupracrustal sequences on both sides of the fault were shown to have different metamorphic degree and apparently different P–T regimes (Alves, 1975). In a broad scale, a higher-grade sequence of peraluminous paragneisses is predominant north of the Guararema Fault, while mica-schists are the main rock type to the south, where low-grade mica schists are locally described (Vieira, 1990).

The southeast limit of the Embu Terrane is defined by the Cubatão Fault, which separates it from a domain that runs along the coastal areas in the State of São Paulo and is largely dominated by a wide variety of deformed granitic rocks. Locally known as the Costeiro or Serra do Mar Domain, this domain is the southwestern continuation of the Oriental Terrane defined by Heilbron et al. (2008), as revealed, among other features, by their lower (Mesoproterozoic) Sm–Nd T(DM) ages (e.g., Campos Neto, 2000).

The granite magmatism, initiated further north in the Rio de Janeiro State as a continental-margin magmatic arc at ~630–620 Ma (Tupinambá et al., 2000), continued here long after its cessation in the Embu Terrane, with the generation of large volumes of (collision-related?) granites and charnockites from 580 to ~560 Ma (Campos Neto and Figueiredo, 1995; Machado et al., 1996). The youngest event of granite generation in this domain is represented by a post-collisional K-rich granite–diorite association derived from enriched mantle and lower crustal sources dated at 510–500 Ma (Wiedemann et al., 2002). According to some authors, the renewed mantle heating revealed by this magmatism may be related to the collapse of a new orogenic belt formed at ~520 Ma by the accretion of the Cabo Frio terrane, exposed in the easternmost portion of the Rio de Janeiro State (Heilbron et al., 2008; Schmitt et al., 2004; Azevedo Sobrinho et al., 2011).

3. Neoproterozoic granitic magmatism in the Embu Terrane

About 30% of the exposed area of the Embu Terrane is made up of Neoproterozoic granites, but few studies have been specifically devoted to these rocks. An old association of orthogneisses occurring as elongated bodies intrusive into the metasupracrustal sequences was recognized in regional studies (Fernandes, 1991). More recently, some of them were dated, and shown to have ages around 800 Ma (811 ± 13 Ma; Shrimp U–Pb zircon dating of a tonalitic gneiss; (Cordani et al., 2002); ~790 Ma; U–Th–total Pb chemical dating of monazite from the Salto Granite; Vlach, 2001). The exact magnitude and significance of this magmatism is still