

ISOTOPIC AND GEOCHRONOLOGICAL CONSTRAINTS FOR THE ORIGIN OF SYN- TO POST-BRASILIANO MAFIC MAGMATISM AND CRUSTAL RE-MELTING IN THE BRASÍLIA BELT (CENTRAL BRAZIL)

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INTRODUCTION

The syn- to post-orogenic stages of the Brasiliano orogeny in central Brazil were characterized by the emplacement of numerous mafic intrusions that occur either associated with larger volumes of K-rich granitic intrusions, within the Neoproterozoic Goiás Magmatic Arc or as individual mafic-ultramafic layered intrusions within the arc and in the so-called Anápolis-Itaçu high-grade Complex, to the east. Until recently, very few geochronological constraints existed for the emplacement ages of these mafic intrusions, and they were mainly indirect ages based on Rb-Sr data for the associated granites (Pimentel et al., 1996). Recent U-Pb zircon and Sm-Nd isotopic data, allied with previous regional geological knowledge, indicate that the Neoproterozoic mafic magmatism played an important role in the Brasiliano tectonic evolution in Central Brazil, and was probably closely related to the heating, crustal re-melting and high temperature metamorphism in both Goiás Magmatic Arc and Anápolis-Itaçu Complex.

REGIONAL GEOLOGY

The Brasília Belt is a large Neoproterozoic orogenic belt developed along the western margin of the São Francisco Craton, Central Brazil. It is composed of four main tectonic segments: (i) a thick Meso-Neoproterozoic metasedimentary/sedimentary pile comprising typical passive margin (Paranoá and Canastra groups) and back-arc (e.g., Araxá and Ibiá groups) successions, and a younger unit (Bambuí Group) probably representing a post-inversion, foreland sequence; (ii) a large Neoproterozoic juvenile arc in its western portion (Goiás Magmatic Arc); (iii) a micro-continent (or allochthonous sialic terrain) formed mainly by Archaean rock units (the Crixás-Goiás granite-greenstones) and Paleo- to Mesoproterozoic mafic-ultramafic high-grade complexes (Barro Alto, Niquelândia and Canabrava complexes), and (iv) a metamorphic core complex comprising felsic granulites and sillimanite-garnet and hypersthene-bearing gneisses and intrusive peraluminous granite, known as the Anápolis-Itaçu Complex, in the central part of the belt.

Two distinct high-grade metamorphic events are constrained in the southern (Anápolis-Itaçu Complex) and northern parts of the Brasília Belt. While high-grade metamorphism in the northern complexes occurred

between ca. 740-780 Ma (Ferreira Filho et al., 1994; Suíta et al., 1994; Correa et al., 1997), granulites in the Anápolis-Itaçu Complex are younger and metamorphic recrystallization took place at ca. 650 Ma (Fischel et al., 1998; Piuzana et al., 2002). Sm-Nd isotopic signature and SHRIMP U-Pb metamorphic ages of the Araxá metasediments and the Anápolis-Itaçu granulites and its intrusive granites (650-640 Ma) are all very similar (Pimentel et al., 1999a; Fischel et al., 1999a, b; Seer, 1999), suggesting that the granulites might represent high-grade equivalents of the Araxá metasedimentary rocks and that at least some of the intrusive peraluminous granites are partial melt products of this metasedimentary protolith (Pimentel et al., 1999a; Fischel et al., 1999a). Mineral assemblage containing sapphirine and quartz in garnet-orthopyroxene-sillimanite granulites of that complex indicates metamorphism at ultra-high temperatures (ca. 1050°C at 10 Kbar) (Moraes et al., 2001), compatible with extensive re-melting of the crust. These new geochronological and isotopic data, therefore, suggest that the Anápolis-Itaçu complex may be now considered to be the metamorphic core complex of the Brasília Belt and not the sialic basement of the Araxá Group (Piuzana et al., 2002). Mafic-ultramafic bodies remained, however, undated, and their tectonic significance, uncertain.

The Goiás Magmatic Arc, in the westernmost part of the Brasília Belt, consists of a large Neoproterozoic juvenile terrane formed by arc-type volcano-sedimentary rocks and tonalite/granodiorite gneisses. It comprises two main magmatic terranes - the Arenópolis and Mara Rosa arcs, located in western and northern Goiás, respectively (Pimentel & Fuck, 1992; Fuck et al., 1994; Pimentel et al., 1997, 2000a, b). In both areas, geological evolution started at ca. 900-860 Ma with the crystallization of very primitive calc-alkaline volcanics and associated tonalites/granodiorites (ϵ_{Nd} values between ca. +3 and +6, and T_{DM} values mostly between ca. 0.8 and 1.1 Ga; Pimentel et al., 1991, 1997, 2000; Pimentel & Fuck, 1992). Geochemical and isotopic data from suggest that the original magmas were formed in an intraoceanic multi-arc system (Pimentel, 1991; Pimentel et al., 1997). Calc-alkaline igneous activity lasted until ca. 640 Ma, and the main deformational-metamorphic episode occurred at ca. 620 Ma, as indicated by U-Pb titanite and Sm-Nd garnet ages (for a review, see Pimentel et al., 2000).

During the waning stages or immediately after the last Brasiliano deformation, a number of small mafic-ultramafic layered complexes, gabbro-dioritic intrusions, and large granite plutons were emplaced into the Goiás Magmatic Arc (Pimentel et al., 1996). In the Arenópolis region, Rb-Sr and U-Pb data suggest that the Brasiliano granite magmatism took place in two distinct episodes: (i) an older event between ca. 590 and 560 Ma, and (ii) a young event dated between ca. 508 and 485 Ma (Pimentel et al., 1996).

THE MAFIC-ULTRAMAFIC INTRUSIONS IN THE ANÁPOLIS-ITAUÇU COMPLEX

Layered, mafic-ultramafic intrusions in the Anápolis-Itauçu Complex form NW-SE elongated bodies, parallel to the regional deformational fabrics of the granulitic country-rocks. Examples of mafic-ultramafic bodies are (i) the Goianira-Trindade Complex, which is made up of pyroxenite, garnet-hypersthene pyroxenite, metagabbro, amphibole schist, and is associated with supracrustal calc-silicate rocks (Nilson & Motta, 1969) and the (ii) Taquaral zoned intrusion comprising gabbros and peridotites marginal to main pyroxenitic and gabbroic units, positioned in tectonic contact with granulite gneissic rocks (Silva, 1997). They frequently display well developed foliation and mylonitic fabrics, however, relict features such as cumulate textures and igneous layering are found in most of the intrusions, attesting to their original layered character (Silva, 1991, 1997).

SYN- TO POST-OROGENIC MAFIC AND ULTRAMAFIC INTRUSIONS IN THE GOIÁS MAGMATIC ARC

In a broad regional scale, the syn- to post-orogenic igneous activity in the Goiás Magmatic Arc is typically bimodal, including large bodies of K-rich calc-alkaline granites (e.g., Serra Negra, Serra do Iran, Caiapó, Iporá, Sanclerlândia and Serra do Impertinente granites) associated with minor gabbro-dioritic end-members. Small mafic-ultramafic layered complexes (e.g., Americano do Brasil and Córrego Lageado complexes) occur as individual bodies. The gabbro-dioritic intrusions and mafic-ultramafic layered complexes are either only slightly deformed or completely free of any pervasive deformational fabric. The gabbro-diorites have typical arc geochemical signature and commonly display magma mixing features with gabbro “globules” enclosed in granitic rocks.

ANALYTICAL PROCEDURES

U-Pb analysis were carried out using SHRIMP I and II at the Research School of Earth Sciences, Australian National University, Canberra. Data were collected and reduced as described by Williams & Claesson (1987) and Compston et al. (1992). Uncertainties are given at 1 σ level, and final age was quoted at 95% confidence level. Reduction of raw data was carried out using Squid 1.02 (Ludwig, 2001a). U/Pb ratios were referenced to the RSES standard zircon FC1 (1099 Ma, $^{206}\text{Pb}/^{238}\text{U}=0.1859$). U and Th concentrations were

determined relative to those measured in the RSES standard SL13.

Sm-Nd isotopic analyses followed the method described by Gioia & Pimentel (2000) and were carried out at the Geochronology Laboratory of the University of Brasília. Sm and Nd samples were loaded on Re evaporation filaments of double filament assemblies and the isotopic measurements were carried out on a multi-collector Finnigan MAT 262 mass spectrometer in static mode. Uncertainties for Sm/Nd and $^{143}\text{Nd}/^{144}\text{Nd}$ ratios are better than $\pm 0.4\%$ (1σ) and $\pm 0.005\%$ (1σ) respectively, based on repeated analyses of international rock standards BHVO-1 and BCR-1. $^{143}\text{Nd}/^{144}\text{Nd}$ ratios were normalized to $^{146}\text{Nd}/^{144}\text{Nd}$ of 0.7219 and the decay constant (λ) used was 6.54×10^{-12} . Isochron ages and parameters were calculated using Isoplot/Ex 2.47 (Ludwig, 2001b).

SHRIMP AND CONVENTIONAL U-Pb RESULTS

Samples from four mafic intrusions - Rio Caiapó gabbro and Serra do Iran diorite, and the Córrego Lageado and Americano do Brasil complexes were selected for U-Pb analyses.

RIO CAIAPÓ GABBRO

Zircon grains from this gabbro are pink, euhedral to subhedral and show strong concentric compositional zoning. Cathodoluminescence images reveal oscillatory zoning and cores of possibly inherited zircon. Only the zoned rims and crystals were analysed. Six analysis have produced a discordia indicating the upper intercept age of 589 ± 19 Ma (MSWD = 0.9).

SERRA DO IRAN DIORITE

Zircon form pink, prismatic stubby crystals. Cathodoluminescence imaging shows thick magmatic concentric compositional zoning. Core might be present, but these were not analysed. Ten spot analysis defined a discordia with an upper intercept age of 623 ± 16 Ma, which agrees with previous Rb-Sr data indicating the isochron age of ca. 622 Ma (Pimentel et al., 1996).

CÓRREGO LAGEADO COMPLEX

Zircon grains are colourless to light pink forming very clear, fracture- and inclusion-free crystals. Cathodoluminescence imaging shows well-developed sector and subordinate concentric compositional zoning. Fourteen analysis yielded concordant results which indicate a concordia age of 672 ± 6 Ma.

AMERICANO DO BRASIL COMPLEX

Most of the grains are long and tabular displaying thick zoning typical of crystals formed in mafic magmas. Cathodoluminescence images show no obvious inherited cores. Magmatic cores are surrounded and embayed by thin and very bright rim, which certainly have low U and Th, and might represent late stage crystallization from the mafic magma.

Eight spot analysis yielded a concordia age of 631 ± 6 Ma. Sm/Nd analysis of mafic and ultramafic rocks from this complex define an isochron (MSWD = 0.9)

indicating the age of 616 ± 81 Ma (2σ), with $\epsilon_{Nd}(T)$ of +2.4. The large uncertainty in Sm-Nd isochron age is caused by the limited spread in Sm/Nd ratio of the samples used.

GOIANIRA-TRINDADE COMPLEX

Zircon grains separated from one leucogabbro sample of this complex were analysed by ID-TIMS. Three concordant analysis yielded the concordia age of 626 ± 2 Ma which is interpreted here as the best estimate for the crystallisation age of the complex.

Sm-Nd ISOTOPIC RESULTS

Sr and Nd isotopic analyses were carried out on thirteen representative samples of the mafic magmatism in Goiás Magmatic Arc, seven of them from the syn- to late-orogenic gabbros and diorites (Rio Caiapó, Serra do Iran, Iporá, Israelândia), and six from the Córrego Lageado and Americano do Brasil mafic-ultramafic complexes. These samples exhibit a relatively narrow range of initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratios from 0.70262 to 0.70363, excluding one sample from the Serra do Iran gabbro with $^{87}\text{Sr}/^{86}\text{Sr}$ ratios of 0.7056. ϵ_{Nd} values calculated for their respective U-Pb crystallization ages vary from slightly negative (-0.75 to -0.32) to positive (+2.1 to +5.5). The Iporá diorite presents moderately negative ϵ_{Nd} value of -2.14, calculated for ca. 500 Ma crystallization age determined for a contemporaneous and spatially associated granite. $^{147}\text{Sm}/^{144}\text{Nd}$ ratios ranging from 0.11 to 0.153 combined with higher than 0.5118 $^{143}\text{Nd}/^{144}\text{Nd}$ ratios provide T_{DM} ages between ca. 1.1 and 0.88 Ga, closely coeval with the rocks from the Neoproterozoic juvenile Goiás Magmatic Arc. T_{DM} ages higher than 1.1 Ga for the Iporá, Serra do Iran and Israelândia diorites seem to indicate some incipient contamination with older crustal rocks.

Sm-Nd isotopic analysis were also carried out in samples from the Goianira-Trindade mafic-ultramafic Complex. These are metamorphosed into amphibolite to granulite facies, however samples used in this study are from outcrops in which igneous textures and structures such as compositional layering and cumulate textures are preserved. Seven samples define an "errorchron" (MSWD = 6.1) with age of ca. 621 Ma. The $\epsilon_{Nd}(T)$ value is close to zero (-0.3), suggesting some degree of crustal contamination of the original magma.

CONCLUSIONS

The SHRIMP U-Pb zircon ages for mafic rocks within the Goiás Magmatic Arc and the Anápolis-Itaçu granulite Complex presented in this study represent the first geochronological constraint for the emplacement age of these rocks. The data suggest that mafic magmatism was important between ca. 670 and 590 Ma, and probably played an important role during the final stages of the Neoproterozoic evolution of this orogen.

Within the Goiás Magmatic Arc, mafic rocks associated with the Serra do Iran, Rio Caiapó and Iporá granite intrusions and both Córrego Lageado and Americano do Brasil complexes indicate that mafic

magmatism was important mainly during late- to post-orogenic stages. Nd isotopic data for these rocks reveal mostly positive $\epsilon_{Nd}(T)$ values between ca. +5.5 and +2.1, indicating the depleted nature of the mantle source and little contamination with older continental crust.

All ages presented in this study overlap with U-Pb titanite and Sm-Nd garnet (between ca. 600 and 630 Ma) ages for metamorphic rocks of the Goiás Magmatic Arc (Pimentel et al., 2000) and with SHRIMP U-Pb ages for granite emplacement and high-grade metamorphism in the Anápolis area (Piuzeana et al., 2002). This suggests that final metamorphism and mafic magmatism took place roughly within the same time interval, and were coeval or shortly followed by uplift, extension and erosion of the orogen (Pimentel et al., 1996, 2003). Uplift was probably more pronounced in the Anápolis-Itaçu Complex allowing exposure of high grade rocks, and also of a larger amount of mafic intrusions, when compared with the Goiás Magmatic Arc.

It is likely that the late Neoproterozoic mafic magmatism have underplated important fractions of the central and western parts of the Brasília Belt continental crust, and may have been responsible for the development of ultra-high temperature metamorphic mineral assemblages, observed in the Anápolis-Itaçu Complex.

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