Accepted Manuscript

Title: Stabilization of the southern portion of the São Francisco craton, SE Brazil, through a long-lived period of potassic magmatism

Authors: Rafael Romano, Cristiano Lana, Fernando F. Alkmim, Gary Stevens, Richard Armstrong

PII: S0301-9268(12)00217-3
DOI: doi:10.1016/j.precamres.2012.09.002
Reference: PRECAM 3624

To appear in: *Precambrian Research*

Received date: 12-12-2011
Revised date: 29-6-2012
Accepted date: 5-9-2012

Please cite this article as: Romano, R., Lana, C., Alkmim, F.F., Stabilization of the southern portion of the São Francisco craton, SE Brazil, through a long-lived period of potassic magmatism, *Precambrian Research* (2010), doi:10.1016/j.precamres.2012.09.002

This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

Here is the highlights in correct form

A large segment of meso-Achaean crust within the São Francisco Craton was transformed into a stable cratonic unit at ca 2700 Ma.

The cratonization occurred during multiple events of potassic granitoid emplacement between 2750 and 2700

The magmatism marks a fundamental change in the tectonics of the craton, with ensuing billion years dominated by clastic and chemical sedimentation

Tables are attached . Please note that the apendix file contains three tables, each of which in a different spreadsheet

Stabilization of the southern portion of the São Francisco craton, SE Brazil, through a long-lived period of potassic magmatism

¹Rafael Romano, ¹Cristiano Lana, ¹Fernando F. Alkmim

¹Departamento de Geologia, Universidade Federal de Ouro Preto, Ouro Preto, MG, Brazil,
35430000

²Gary Stevens

²Department of Earth Sciences, University of Stellenbosch, Private Bag XI, Matieland 7602, South
Africa

³Richard Armstrong

³Research School of Earth Sciences, The Australian National University, Canberra 0200. A.C.T.
Australia

Keywords: Potassic grantoids, U-Pb geochronology, Neoarchaeon, Quadrilátero Ferrífero, São
Francisco craton, Brazil

Abstract- Although the southern portion of the São Francisco craton in southeast Brazil encompasses one of the largest segments of Meso- to Neoarchaeon crust in the South American plate, there is little understanding of the processes leading to cratonization of this region. Our combined field and U-Pb age data show that the crust experienced massive intrusions of potassic (K-rich) granitoids between 2750 and 2600 Ma, and that this magmatic event marked the beginning of a fundamental change in the tectonics of the terrain, with the ensuing billion years being dominated by the deposition of a series of thick clastic and chemical sedimentary successions. Thus, deep crustal partial melting and subsequent transport and intrusion of these granites in the upper crust is a likely mechanism by which this segment of the São Francisco crust attained buoyancy to survive recycling. Regional mapping indicates that the potassic granitoids are distributed over an area of $\sim 25000 \text{ km}^2$, and are related to one of the most prolific periods of potassic magmatism in the craton. LA-ICP-MS and SHRIMP U-Pb data from 16 samples of potassic granitoids together with published TIMS ages suggest a long lived period of magmatism from 2750 to 2700 Ma, and a small pulse of granite crystallisation at ca. 2612 Ma. The U-Pb SHRIMP and LA-ICP-MS data also indicate that the Archaean granitoids do not record evidence of U-Pb zircon resetting. Our interpretation is that partial melting and transport of granitoid melts (rich in heat producing elements) to the upper crust gave rise to a thermally stable lower crust and that this lower crustal segment (in the craton area) became sufficiently refractory and resistant to further partial melting.

1. Introduction

The withdrawal of large volumes of potassium-rich magmas from the deep continental crust and their emplacement at higher structural levels is a common process of many Archaean provinces worldwide (Anhaeusser and Robb 1983; Robb et al., 1983; Taylor and McLennan, 1985; Sylvester, 1994). This type of intracrustal magmatism generates high-K, calc-alkaline granites and granodiorites, which often occur later in the tectonic history of the provinces, following the assembly of older tonalite-trondhjemite-granodiorite (TTG) crust (e.g., Wells, 1981; De Wit et al., 1992;

Kusky, 1993; Poujol et al., 2003; Lana et al., 2004; Jayananda et al., 2006; Drüppel, et al., 2009). Despite current uncertainties about sources and tectonic settings, the generation and emplacement of such potassic magmas seem to play a major role in the thermal stabilization of Archaean lithosphere (e.g., Kusky, 1993; De Wit et al., 1992; De Ronde and De Wit 1994; Moser et al., 1996; Dirks and Jelsma, 1998; Kusky and Polat, 1999). This is particularly so for events where the partial melting and upward migration of felsic magmas lead to extensive removal of heat producing elements (HPEs) from the deep crust, and substantially reduce the long-term heat production in the source of melting (Sandiford and McLaren, 2002; Sandiford et al., 2002, 2004). Consequently, a number of integrative models of crust and mantle structure argue that the partial melting with upward migration of voluminous felsic magma results in a stratified lithosphere, with granite-rich upper crust and thermally stable (residual) lower crust and upper mantle (Kusky, 1993; Moser et al., 2001, Lana et al., 2003, 2004; Armstrong et al., 2006).

In the southern segment of the São Francisco craton, southeastern Brazil (Fig.1), potassic granitoids together with tonalite-trondhjemite-granodiorite (TTG) rocks and greenstone belt strata comprise one of the oldest Archaean continental shield areas of South America. Within this terrain, the potassic granitoids are demonstrably younger than the TTG counterparts (Teixeira et al., 1996; 2000; Machado et al. 1992, Machado and Carneiro, 1992; Noce et al., 1998), and their widespread distribution seem to mark a distinct change in the tectonothermal regime of the crust during growth of the craton in the Neoarchaeon. Previous studies have shown clear geochemical and age differences between the TTG and potassic granitoids, and suggest a transition from sodic (TTG-dominated) to a more potassic (granite-dominated) magmatism at ca. 2780-2750 Ma (Romano, 1989; Carneiro, 1992, Noce, 1995, Noce et al., 1997; Carneiro et al., 1997). A significant portion of the potassic granitoids remained undeformed since crystallisation; they testify to the main crustal thickening event during stabilisation of the Archaean crust. However, important constraints on this potassic magmatic event such as the timing, extent, and the crustal modifications associated with it have not been investigated.

A systematic age dating study of the potassic granitoids would provide unique insights into the evolution of a yet poorly constrained segment of Archaean crust in South America as well as into the process of growth and stabilization of one of the oldest building blocks within the São Francisco craton. Here, we report results of a U-Pb single zircon geochronology study of numerous potassic granitoids of the southern portion of the craton (Fig. 1). The TTG and potassic granitoids are exposed along km-scale structural domes that are in sharp tectonic contact with deeply rooted keels of Archaean to Palaeoproterozoic greenstone and clastic-chemical strata (Marshak et al., 1992; Machado et al., 1996; Alkmim and Marshak., 1998). We focus our observations on the spatial distribution and timespan of the Neoarchaean potassic granitoid emplacement. In the light of our U-Pb (LA-ICP-MS and SHRIMP) data, we further explore field observations and existing U-Pb TIMS ages to test the link between the potassic magmatism and the consolidation of this portion of the São Francisco craton.

2. Geological Setting

The São Francisco craton, located in the eastern portion of the Precambrian core of South America (Fig. 1), is subdivided into several Archaean to Paleoproterozoic blocks that are bounded by major 2100 and 2000 My old sutures zones (Almeida et al., 1981, Teixeira and Figueredo, 1991; Ledru et al., 1994; Teixeira et al., 1996, 2000; Barbosa and Sabaté, 2004). The main crustal segment of the craton seems to form a coherent NS-trending block, which represents an Archaean core to which various terranes have been accreted during the Palaeoproterozoic (Alkmim, 2004) (Fig.1). This block, known as the Gavião block among geologists working in the northern half of the craton (Teixeira and Figueredo, 1991; Teixeira et al., 1996, Barbosa and Sabaté, 2004), corresponds to the ancestor Paramirim craton (Almeida 1981), and as such represents one of the largest and oldest segments of Archaean crust in the South America. For simplicity it will be referred to as the Gavião block in this paper (Fig.1).

The southern portion of the Gavião block, hereafter described as the Southern São Francisco craton (Figs. 1), was formed during multiple stages of TTG and potassic granitoid plutonism in and around polydeformed greenstone belt sequences between 3200 Ma and 2600 Ma (Carneiro, 1992, Noce, 1995, Teixeira et al., 1996; Machado et al., 1996). After the latest magmatic event, the crust experienced extension and accumulation of a thick Palaeoproterozoic succession of clastic and chemical strata of the Quadrilátero Ferrífero (QF) mining district (Fig. 2). Early field-based stratigraphic studies (Dorr et al., 1957; Dorr, 1969) have subdivided the QF strata into three major units - the Rio das Velhas and Minas Supergroups, as well as the Itacolomi Group (Figs. 2, 3). Subsequently, SHRIMP and TIMS U-Pb age dating of crystalline and supracrustal rocks (Machado et al., 1992, 1996; Noce et al., 2005; Hartmann et al., 2006) have provided important constraints on the timing of magmatic/volcanic events as well as the maximum age of deposition of numerous subunits within the Rio das Velhas and Minas Supergroups (Figs. 2, 3). The stratigraphic and timeline sequence synthesised from this data (Fig. 3) provides a background for a brief summary of the magmatic and depositional episodes in the QF.

The crystalline crust is mainly exposed in km-scale basement domes (e.g., Teixeira et al., 2000), which include the Bonfim, Bação, Belo Horizonte, Santa Rita, Caeté and Florestal domes (Fig. 2). The largest of these domes (Belo Horizonte, Bação and Bonfim) are characterised by Meso- to Neoarchaeon (3200-2870 Ma) crystalline TTG rocks (gneisses and migmatites), and small occurrences of greenstone strata deformed under greenschist to amphibolite facies metamorphic conditions (Herz, 1970, 1978; Carneiro et al., 1997; Noce et al., 1998; Machado et al. 1992). The TTG rocks in the Belo Horizonte dome record a period of high-grade metamorphism, with formation of a penetrative amphibolite-facies foliation and local development of banded/stromatic migmatites. Noce et al. (1998) obtained a U-Pb upper intercept TIMS age of 2860 ± 14 Ma from the migmatite, and interpreted this age as the timing of high-grade metamorphism and partial melting of TTG crust older than 2.9 Ga. The migmatism event was followed by the intrusion of a second generation of TTG magmas, with the emplacement of large bodies of tonalites and granodiorites in the eastern

and western parts of the QF (the Caeté and Samambaia granitoids, Fig. 2) at 2776 ± 7 Ma and 2780 ± 3 Ma (Machado and Carneiro, 1992; Machado et al., 1996; Noce et al. 1998).

The deposition of the Rio das Velhas Supergroup took place between 3000-2600 Ma (Machado et al., 1992; Noce et al., 1998, 2005) (Fig. 3). The unit consists of a complex sequence of mid- to late-Archaeon mafic-ultramafic lavas overlain by late Archaeon volcanics and sedimentary rocks (Fig. 3). The supergroup is subdivided into three units – the Quebra Ossos, Nova Lima and Maquiné Groups (Dorr, 1969, Ladeira, 1980, 1981, Zuchetti et al., 1998) (Figs. 2, 3). The basal Quebra Ossos Group consists of dominantly mafic and ultramafic metavolcanics, which display spinifex textures and pillow structures with variolitic margins (Ladeira, 1980, 1981). The intermediate Nova Lima Group sequence includes basic and felsic lavas, greywackes, quartzites, banded iron formation, quartz–dolomite and quartz–arenite (Gair, 1962). SHRIMP and TIMS data from several felsic lavas and greywacke samples across the QF indicate ages of 2772 ± 6 Ma, 2776 ± 26 Ma, 2792 ± 11 Ma, 2773 ± 7 Ma and 2751 ± 9 Ma (Machado et al., 1992; Noce et al., 2005). The Nova Lima Group clastic sediments are in gradational contact with overlying Maquiné Group - a 2000 m-thick sequence of phyllite and quartz–phyllite of the Palmital Formation (O'Rourke, 1957) and quartz schist, conglomerate, phyllite and greywacke of the Casa Forte Formation (Gair, 1962).

The overlap between the second phase of TTG magmatism and the widespread Rio das Velhas volcanism in the QF, indicate that the Southern São Francisco craton was already amalgamated into a coherent entity by 2780-2750 Ma. Subsequent to this amalgamation, the Archaeon crust experienced widespread potassic granitoid emplacement (Fig. 3; e.g., Carneiro, 1992; Noce 1995) and concomitant mid-crustal metamorphism, recorded to the southwest of the QF (Campos et al., 2003). Unpublished geochemical data for several of these granitoids (e.g., Brumadinho, Souza Noschese, Santa Luzia, General Carneiro, Ibirité, Salto do Paraopeba) indicate that they are high-K calc-alkaline to shoshonitic granites with peraluminous to metaluminous compositions (Carneiro, 1992; Noce, 1995). They are also substantially enriched in $\text{Na}_2\text{O}+\text{K}_2\text{O}$ and LREE relative to the host TTG rocks and contain negative Eu anomalies (Carneiro, 1992; Noce, 1995; Noce et al., 1998;

Carneiro et al., 1997). Limited U-Pb TIMS ages from five relatively small granite plugs suggest a 100 Ma period of potassic magmatism spanning from 2712 Ma to 2614 Ma (Carneiro, 1992; Noce, 1995).

The potassic magmatism was followed by several surface processes including the accumulation of the Palaeoproterozoic Minas Supergroup, which unconformably overlies the Rio das Velhas Supergroup (Dorr, 1969). According to Machado et al. (1996) the onset of deposition of the Minas sediments is related to thermal relaxation during or after cessation of the potassic magmatism. The sequence is represented by alluvial sandstones, conglomerates and shallow-water pelites (Caraça Group), banded iron formations and carbonates (Itabira Group), deltaic, shallow water strata (Piracicaba Group) and a syn-orogenic (flysch) succession of turbidites, tuffs, volcanoclastics and conglomerates (Sabará Group) (Dorr 1969, Renger et al., 1995; Alkmim and Marshak, 1998; Reis et al., 2002, Alkmim and Martins-Neto, 2011) (Fig. 3). The Caraça and Piracicaba Groups contain zircons derived predominantly from the Archaean granitoids, with the grains ranging in age from 3250 to 2580 Ma (Caraça Group), and from 3353 to 2775 Ma (Piracicaba Group) (Machado et al. 1996; Hartmann et al., 2006) (Fig. 3). Lead isotopic studies (Babinski et al., 1995) indicate that the subsequent chemical sedimentation of the carbonates and iron formations of the Itabira Group occurred at ca. 2420 ± 20 Ma, whereas the accumulation of the shallow water deltaic sequence of the Piracicaba Group took place during a period of slow subsidence of the entire basin after 2420 Ma. In contrast, the overlying Sabará Group is considerably younger, containing detrital zircons of ca. 2120-2130 Ma (Machado et al., 1992; 1996). The deposition of this unit is linked to an collisional event along the eastern margin of the craton during the Palaeoproterozoic orogeny at 2100-2000 Ma (Alkmim and Marshak, 1998, Alkmim and Martins-Neto, 2011).

3. Potassic granitoid suite

In an attempt to provide constraints on the extent and timing of the main pulse of potassic granitoid magmatism in the Southern São Francisco craton we have documented the distribution, intrusive relationships and ages of plutons that are distributed over an area of ~25.000 km² in and around the QF province (Fig. 2). The potassic granitoids comprise at least 30% of the bulk of the Archaean crust (TTG + granitoids), currently exposed in the study area (e.g., Bonfim and Belo Horizonte granitoid-gneiss complexes; Fig. 2).

Detailed mapping in the Bonfim dome and in the northwestern margin of the Belo Horizonte dome (Fig. 4a, b) indicate that the potassic granitoids are erosive remnants of batholiths or extensive horizontal sheets. The massive sheets are largely preserved along km-long ridges, and sustain much of the topography along the contact with the supracrustal rocks (Fig. 4b). Here, the granitoids are either in intrusive contact with the Rio das Velhas strata, or in sharp tectonic contact with either Rio das Velhas or Minas Supergroup strata (e.g., Noce, 1995; Alkmim and Marshak, 1998). The topographically lower (eroded) interior of the domes is defined by steeply-dipping, amphibolite-facies TTG gneisses that are intruded by multiple, m-scale granitoid sheets and dykes (Figs. 4b and 5a-d). Some granitoid bodies intrude sub-parallel to the TTG gneissosity (Fig. 5b) and are crosscut by younger texturally and mineralogically distinct granitoid phases (e.g., Fig. 5c-d). The older granitoid sheets are marked by a weak solid-state fabric with regionally consistent trends, indicating a pre- to syn-tectonic timing of emplacement. The younger granite phases (massive granitoids of the core of the batholiths – e.g., Fig. 5f-h) are, in contrast, devoid of solid-state fabrics. Such phases also contain cm- to m-scale xenoliths of the host TTG gneiss and may locally record a magmatic fabric defined by aligned feldspar megacrysts and cm-wide biotite clots.

Batholiths such as the Florestal, Pequi, Souza Noschese and Mamona are made up of at least three main phases of granitoid intrusions, which cover a wide range in composition from a megacrystic granodiorite, milky-white microcline-bearing granodiorites, to a pinkish K-feldspar-rich syenogranite (Fig. 5d-f). The oldest phases are represented by weakly-foliated medium-grained granodiorite phases, consisting of plagioclase, quartz, biotite and microcline (e.g., Fig. 5c, d). This phase is directly intruded into foliated TTG gneisses and is cross cut by weakly foliated medium- to

coarse-grained granodiorites and granites, with abundant plagioclase and substantially less biotite than the older granodiorite phase (Fig. 5d, e). The youngest phase is a milky-white, non-foliated leucogranite that consists predominantly of plagioclase, quartz and microcline (Fig. 5f, g). Some of these youngest granitoid phases contain tourmaline as an accessory mineral.

Two other small bodies - the Piracema and General Carneiro granitoids - were emplaced into the Bonfim and Belo Horizonte domes, respectively. The Piracema body is a six km-long, two km-wide body of a pinkish-medium grained syenogranites (Fig. 5g), located in the southern margin of the Bonfim Complex. It consists predominantly of plagioclase, K-feldspar, quartz and minor biotite. Observations at several outcrops show that the syenogranite contains numerous xenoliths of a banded, strongly folded gneiss, representative of the oldest TTG phase in the Bonfim Complex. The General Carneiro Granitoid (Fig. 5h), located in the northeastern sector of the study area, comprises a 2 by 1 km body intruded into the Belo Horizonte Complex and juxtaposed with the Sabará schists (Minas Supergroup) along a shear zone.

4. Geochronology

4.1 Samples

LA-ICP-MS and SHRIMP U-Pb age data were obtained from 16 samples distributed across the Belo Horizonte, Bonfim and Bação domes (see Appendix A for details on the U-Pb age dating methodology). This includes samples from the batholiths – Pequi, Florestal, Mamona, Souza Noschese - and samples from small intrusions into the TTG gneisses. Nearly all granitoid rocks sampled yielded a large number of zircons, of which only a fraction (20-60% - depending on the sample) were suitable for dating via spot analysis. As previously observed in other granitoids from the QF (e.g., Machado et al., 1992), the bulk of the zircons extracted from each sample were largely turbid, ranging in colour from milky white to dark brown. Because these grains were largely metamict and rich in mineral inclusions (apatite and Fe-oxides), they produced unreliable U and Pb

counts during ablation (see also Machado et al., 1992, Machado and Carneiro, 1992). Hence, this study reports U-Pb age data from fractions that preserved euhedral to subhedral forms and were predominantly translucent. Such grains were analysed after careful selection and SEM-cathodoluminescence (CL) imaging. The CL images and the U-Pb dataset for the potassic granitoids can be found in the electronic supplementary information to this paper (Appendices B and C, respectively).

4.2 Belo Horizonte dome

4.2.1 Florestal batholith (Sample MR234A)

Sample MR234A (UTM 7808488/550202) was collected from a coarse-grained locally porphyritic granodiorite in the central part of the Florestal batholith (Fig. 5c). The granodiorite is characterised by mm- to cm-wide microcline crystals embedded in a granoblastic matrix of plagioclase, biotite and quartz. In most places, this rock exhibits a prolate L>>S fabric, defined by aligned crystals of biotite and stretched rods of quartz and plagioclase. Zircons extracted are translucent to slightly turbid, ranging in colour from white to brown. The grains were dominantly long-prismatic, although short-prismatic forms were also present. Rare inclusions of apatite and Fe-oxides were observed in largely fractured grains. CL images exposed well-defined oscillatory zoning and clear core-overgrowth relationships. Most cores were CL-brighter than the overgrowth or were veneered by bright rims. Overgrowths showed perfect concentric oscillatory zoning. Spot analyses in the core were highly discordant, except for two subconcordant points (<1% discordant) that gave apparent $^{206}\text{Pb}/^{207}\text{Pb}$ ages of 2849 ± 22 Ma and 2916 ± 21 Ma. The oscillatory overgrowth yielded concordant to subconcordant points that plot along a recent Pb-loss Discordia with an upper intercept age of 2758 ± 5 Ma (MSWD=0.82) (Fig. 6a). Nine concordant points give identical Concordia age of 2755 ± 8 Ma (MSWD=1.0). Both ages are within error of a 2755 ± 14 Ma age (Romano 1989) from a sample collected in the southern margin of the batholith. We interpreted the 2755 ± 8 Ma Concordia age as the crystallisation age of this sample.

4.2.2 Pequi batholith (Samples MR231A, MR259A, MR257)

Sample MR231A (UTM 783777/535781) is a medium-grained grey granodiorite that represents the oldest phase in the Pequi batholith (Fig. 5d, phase i). The sample yielded only turbid, milky white to brown, stubby zircons, which range in size from 100 to 450 μm . The grains were fractured and contained inclusions of apatite and Fe-oxides. The least turbid grains showed internally consistent oscillatory zoning under CL and no obvious core structures. Most analyses were severely discordant and revealed remarkably low concentrations of Pb and Th. For example, the turbid grains gave highly discordant ages that seem to define a Concordia with an upper intercept age ~ 3200 Ma. We interpret these grains as inherited. Points with consistently high Pb and Th contents seem to define a Pb-loss chord that intercepts Concordia at 694 ± 110 Ma & 2750 ± 13 Ma (MSWD = 0.49) (Fig. 6b). The upper intercept age is interpreted as the best approximation of the crystallisation age of this sample.

Sample MR259A (UTM 7834072/539550) represents a medium-grained granite phase in the central part of the Pequi batholith (Fig. 4a). The granitoid (Fig. 5d, phase ii) crosscuts the grey granodiorite phase and is intruded by leucogranite phases. The sample was collected from a large pavement located a few kilometres southeast of sample MR231A. It contains zircons that are clear, pink to brown and prismatic. Some grains were slightly milky white, stubby and prismatic. Rare inclusions of apatite and Fe-oxides were observed. CL images revealed predominantly structureless crystals, with some grains recording a poorly defined internal zoning. Some grains were largely bright but surrounded by dark (altered) rims. Some bright cores were clearly resorbed and overgrown by darker rims. Spot analyses show variable degrees of discordance (0-50%), with no coherent Pb-loss trend. The cores of the grains were largely enriched in U and Th - four subconcordant cores (<3% disc.) gave a mean $^{206}\text{Pb}/^{207}\text{Pb}$ age of 2769 ± 21 Ma. Analyses on the structureless grains showed much lower U and Th contents and younger $^{206}\text{Pb}/^{207}\text{Pb}$ ages. The concordant points gave a Concordia age of 2722 ± 7 Ma (MSWD=0.9) and a mean $^{206}\text{Pb}/^{207}\text{Pb}$ age of 2723 ± 12 Ma (Fig. 6c).

Given the field observations that this rock is intrusive into the 2750 Ma porphyritic phase (e.g., Fig. 5d), we suggest that the 2769 Ma age is inherited, whereas the crystallisation age of this sample is interpreted to be 2722 ± 7 Ma.

Sample MR257A (UTM 7835513/537893) represents a coarse grained, biotite-poor granitoid that cross cut the biotite-rich granodiorite (sample MR259A). The granitoid occurs as large vertical sheets or thin irregular veins intruded into the granodiorite (e.g., Fig. 5e). The extracted zircons were largely clear, pale yellow to brown. Most grains ranged from short-prismatic to stubby, showing slightly round termination. Rare inclusions of apatite and Fe-oxides were observed. CL-images exposed oscillatory zoning. Some of the grains show roundish cores sharply truncated by oscillatory overgrowth. Several attempts to obtain ages for cores have failed due to the high level of discordance. This excludes one analysis that gave an 8% discordant $^{206}\text{Pb}/^{207}\text{Pb}$ age of 2938 ± 19 Ma. Oscillatory overgrowths ranged from concordant to highly discordant and variable U-Th contents. The most translucent grains yielded concordant to subconcordant points (<5% disc.), and slightly more consistent U-Th values. These grains plot along a regression line with upper and lower intercept ages of 2707 ± 7 Ma and 160 ± 290 Ma (MSWD=1.3) (Fig. 6d). Twelve points (<1% disc.) give a Concordia age of 2706 ± 7 Ma (MSWD=0.66), which is interpreted as the crystallisation age of the sample.

4.2.3 Small intrusion (Sample MR51A)

One sample of the General Carneiro Granitoid (sample MR51A) was collected in the southern extremity of the Belo Horizonte dome (UTM 7803440/621958), a few kilometres north of the contact with the Sabará Formation. This phase is a medium-grained, milk-white leucogranite, consisting of predominantly microcline, plagioclase and quartz. The sample contains zircons that are clear, inclusion-free, ranging in colour from pale yellow to light pink. Most grains were short-prismatic (100-200 μm long) with some round terminations and resorbed margins. CL imaging shows well-defined concentric zoning. No obvious core structures were observed. Some grains showed clear

corroded margins that were overgrown by low-CL rims. Fourteen analyses on the centre and rims of these grains give consistent U-Pb ages, with a number of concordant and subconcordant points that plot around 2700 Ma. Regression analysis of the data gives a recent Pb-loss cord that intercepts the upper Concordia at 2702 ± 6 Ma (MSWD = 1.0) (Fig. 6e). The concordant points (11 points <1% disc.) yield an identical Concordia age of 2700 ± 8 Ma, which is here interpreted as the crystallisation age of the granitoid.

4.3 Bonfim dome

4.3.1 Mamona batholith (Samples MR14A, MR70G, MR87A)

Sample MR14A (UTM 7756333/608654) was collected in the northeastern margin of the Mamona batholith (Fig. 3). It is a non-foliated, coarse-grained granitoid that consists of plagioclase, microcline, quartz, and biotite clots; the clots range in size from a few millimetres to several centimetres wide (Fig. 5e). This granitoid phase is the most voluminous and hence the most representative of the core of the batholith. Only a small fraction of the zircon separate in this sample (comprising 25 grains) were sufficiently translucent for U-Pb dating. The zircons were dominantly long-prismatic, white to pale yellow. CL-images show well-defined zoning with core and overgrowth structures. The majority of the analysis in the core of these grains gave highly discordant points in the Concordia diagram – no intercept age has been attempted. Two subconcordant points may suggest that these cores are older than 2.9 Ga. Analyses on the oscillatory overgrowths are substantially concordant. They plot along a Pb-loss Discordia with intercept ages of 815 ± 130 Ma and 2728 ± 7 Ma (MSWD=0.84). The upper intercept age is similar (within error) of a Concordia age of 2730 ± 7 Ma given by 8 concordant (<1.1% disc.) points (Fig. 7a). We interpret the Concordia age as the crystallisation age of the granitoid.

Sample MR70G (UTM 7727899/602011) was collected in the southern extremity of the Mamona batholith. It is a non-foliated, coarse-grained leucogranite that contains similar amounts of

plagioclase, microcline, quartz, and minor biotite. The sample yielded a number of prismatic zircons that were clear, pink to light brown. The predominant zircon type is light brown in colour, needle-like in shape and has lengths varying from 110 to 150 μm . Rare inclusions of apatite and Fe-oxides were observed. CL images show well-defined oscillatory zoning, except for a few prismatic, euhedral grains that were entirely bright, or bright with thin dark rims. Some resorbed dark cores were observed in many of the grains. Spot analyses in these cores were very discordant and no coherent age data could be obtained; e.g., $^{206}\text{Pb}/^{207}\text{Pb}$ ages ranged from 3.5 to 2.8 Ga. In contrast, spot analyses on the oscillatory zones were largely concordant – only three points were discordant (6-8% disc.). All the points define a regression line with upper and lower intercept ages of 1000 ± 160 Ma and 2723 ± 8 Ma (MSWD=1.3), whereas the eleven concordant points (<1% disc.) gave a nearly identical Concordia age of 2723 ± 7 Ma (Fig. 7b), which is here interpreted as the crystallisation age of the leucogranite.

Sample MR87A (UTM 7738759/ 608581) is a foliated, fine- to medium-grained grey granodiorite intruded in the eastern part of the Mamona batholith (e.g., Fig. 5f). The rock consists of strongly recrystallised quartz, plagioclase and microcline and aligned cm-wide clots of biotite. Crosscutting pegmatites are also present. The translucent zircons from this sample were pale yellow to pink. Most grains were long and prismatic (>200 μm long), but some stubby grains were present. CL-imaging exposed (1) structureless (dark) cores or bright overgrowths, (2) complex growth structures as well as (3) defined oscillatory zoning. A few grains showed corroded margins, and others showed obvious truncations between older cores and overgrowth rims. The structureless cores and grains with corroded margins yielded 11 points that were concordant to slightly reversely discordant. These points give a $^{206}\text{Pb}/^{207}\text{Pb}$ weighted mean age of 2635 ± 12 Ma. Point analyses on the oscillatory rims vary from concordant to reversely discordant. Fourteen analyses on prismatic grains (with well-defined oscillatory zoning) were concordant (<1% disc), yielding a slightly younger U/Pb Concordia age of 2613 ± 6 Ma (MSWD=0.4) (Fig. 7c), and is here interpreted as the crystallisation age of the sample.

4.3.2 Souza Noschese batholith (Samples MR22A, MR148A, MR31A)

Sample MR22A (UTM 7769392/602440) represents an aerially extensive intrusion in the Souza Noschese batholith. It is a medium-grained, weakly foliated, grey granodiorite that intrudes strongly foliated banded gneiss, in the northeastern margin of the Bonfim complex. The rock is mineralogically and texturally identical to the granodiorite in the Pequi batholith (MR259A). It contains strongly recrystallised plagioclase, quartz, microcline and aligned biotite clots. The extracted zircons are dominantly clear brown, short prismatic grains, with round terminations. Rare inclusions of apatite and Fe-oxides were observed. CL-images show well-defined oscillatory zoning for most grains, although some grains were structureless. Analyses on both types of grains plot along a recent Pb-loss chord with a lower intercept age of 266 ± 170 Ma and an upper intercept age of 2727 ± 6 Ma (MSWD=1.05)(Fig. 7d). The concordant points (<1% disc.) yield a Concordia age of 2730 ± 8 Ma (MSWD=0.8), which is slightly older, but within error of the intercept age. We suggest that this sample crystallised at 2730 ± 8 Ma.

Sample MR148A (UTM 7757998/573730) was collected in the southwestern margin of the Bonfim Complex. It represents a milky-white, biotite poor leucogranite that intrudes strongly foliated banded gneiss (Fig. 5g). Zircons from this sample were largely altered, ranging from turbid brown to milky white and ranging in size from 200 to 350 μm . They are dominantly anhedral, but some were short-prismatic, with round terminations. Some round and irregular shapes were observed. CL-images were also poorly defined, where some oscillatory zoning could be identified in some grains. Some grains seem to have brighter cores, but the relationship with the overgrowing zoning could not be completely discerned. Twenty one analyses on these zircons yielded variable U/Pb ages with a number of analyses showing severe discordance. Nevertheless, regression analysis of all data yields an upper intercept age of 2719 ± 10 Ma (MSWD = 1.8) and lower intercept age of 121 ± 140 Ma (Fig. 7f). Five of these analyses are concordant (1.5% disc.) and give a Concordia age of 2722 ± 9 Ma. This Concordia age is identical to the age obtained for sample MR 70A and is interpreted as the crystallisation age of the leucogranite.

Sample MR31A (UTM 7775356/594650) comes from a non-foliated leucogranite in the northern extremity of the batholith. Similarly to sample MR148A, it consists dominantly of plagioclase microcline and quartz. The extracted zircons were predominantly turbid, milky white to light brown and prismatic. Only a small percentage of these grains (2%) was partly translucent, light brown, and long-prismatic with round terminations. The white crystals vary in length from 100 to 200 μm , whereas brown grains were significantly larger (up to 300 μm). Inclusions of apatite and Fe-oxides were observed in nearly all grains. CL images exposed well-defined oscillatory zoning, with no clearly discernible cores, but a few grains record resorbed rims. Twelve analyses on the centre and margins of these grains plot along a line that intercepts Concordia at 519 ± 57 Ma and 2697 ± 6 Ma (MSWD=1.0) (Fig. 7g). The concordant grains (5 translucent grains, <1% disc.) give a similar, but more precise, Concordia age of 2700 ± 8 Ma (MSWD=1.12) that is here interpreted as the crystallisation age of the leucogranite.

4.3.3 Small intrusions (Samples MR10A, MR10C, MR137G)

Two vertical granitoid intrusions (MR10A, MR10C) were sampled in the central portion of the Bonfim Complex. Sample MR10C (UTM 7770990/588201) represents to a grey biotite-rich granodiorite intruded in banded TTG gneisses. The granodiorite contains a solid-state foliation defined by aligned biotite clots and stretched plagioclase and quartz. Despite the number of grains affected by radiation damage, several light brown, translucent grains were recovered. These grains range from prismatic to stubby, most of which contain round terminations. CL-images reveal concentric zoning with some grains showing bright and dark centres. The dark centres were commonly rimmed by CL-bright zones. All points analysed here plot along a line that intercepts the lower and upper Concordia at 898 ± 64 and 2729 ± 9 Ma, respectively (Fig. 8a). The upper intercept age is identical to the ages of granodiorites in the Souza Neschese and Mamona batholiths and is here interpreted as the crystallisation age of the sample.

Sample MR10A (UTM 7770990/588201) was collected a few metres away from sample MR10B in the central portion of the Bonfim dome. It is a non-foliated biotite-poor granodiorite, containing plagioclase, microcline, quartz and minor biotite. Several sheets of this granodiorite cross cut the grey biotite-rich granodiorite (sample MR10B). Zircons from MR10A contain a well-defined oscillatory zoning, with bright and dark cores. A few grains contained low-CL cores with visible truncation with the surrounding oscillatory rims. Other grains showed visible resorbed rims. Three analyses from these cores gave an upper intercept age of 2774 ± 7 Ma (Fig. 8b), which is identical to the crystallisation (TIMS) age of the Caeté TTG Gneiss (2776 ± 7 Ma, see Fig. 2; Machado et al., 1996). The oscillatory zoning gave a much younger age of 2719 ± 5 Ma (MSWD=0.48), which is here interpreted as the crystallisation age of the granitoid.

The Piracema Granitoid is a pinkish leucogranite rich in K-feldspar, quartz and plagioclase (Fig. 5h). This phase is intrusive into strongly foliated TTG gneisses and is characterised by numerous xenoliths of the host TTG rocks. Sample MR137G (7741294/568049) was collected from a river pavement in the southern part of the granitoid. It yielded a small fraction (~15%) of translucent brown zircons that were predominantly short-prismatic (200 μ m long). CL-images indicate a poorly defined oscillatory zoning. Some grains showed corroded margins and distinguishable core-overgrowth relationships. Spot analyses from the core of these zircons were, however, highly discordant, with ambiguous U-Pb ages. Analyses from both clear and turbid grains, devoid of core-rim structures, plot about a Pb-chord that intercepts Concordia at around 2700 Ma. The translucent grains yielded the most concordant to sub-concordant points (11 points) that define a recent Pb-loss Discordia line that intercepts the Concordia at 69 ± 270 Ma and 2706 ± 5 Ma (Fig. 6m). An identical (but more conservative) Concordia age of 2708 ± 7 Ma (MSWD=1.3) is given by the concordant grains (<1.5 % disc.) (Fig. 8c). The Concordia age is interpreted as the crystallisation age of the granitoid.

4.4 Bação dome

4.4.1 Granodiorite (Sample MR11)

Sample MR11 (UTM 7762152/625597) represents a medium-grained grey granodiorite collected in the northern margin of the Bação dome. The granodiorite is intruded into banded TTG gneiss and records a weak lineation defined by aligned biotite and elongated plagioclase-quartz rods. It consists of biotite, plagioclase, quartz and microcline. Zircons from the sample range from pale-yellow to brown and are dominantly stubby with round terminations. Most grains are zoned with some broad zones of intense alteration and radiation damage. CL images reveal a well-defined oscillatory zoning, with discernible core-rim relationships. The low-CL core of the grains yielded a number of discordant points with apparent $^{207}\text{Pb}/^{206}\text{Pb}$ ages that range from 2826 to 2893 Ma. Although the analyses show severe disturbance (Pb-loss), the points seem to align along a Pb Discordia that intercepts the upper Concordia at 2909 ± 19 Ma (MSWD=1.5). This age is within error of the crystallisation age of the banded TTG gneisses from the Bonfim dome (e.g., Machado and Carneiro, 1992). Twelve analyses from the rim of these grains plot along a regression line that intercepts the Concordia at 428 ± 42 Ma and 2747 ± 16 Ma. An identical, but more precise upper intercept age of 2744 ± 10 Ma (MSWD=1.4) is obtained (Fig. 8d) if only two of the most discordant grains are excluded (grains 8 and 11; Appendix C). This age is interpreted as the best approximation of the crystallisation age of the granodiorite.

4.4.2 Granite (Sample MR01)

Sample MR01 (7746959/643228) represents a medium- to coarse-grained, biotite-poor granite intruded in the southern margin of the of the Bação dome. The granite is in tectonic contact with the surrounding supracrustal rocks of the Minas Supergroup and preserves a weak foliation that parallels with the SE-dipping bedding of the Moeda Formation. Zircons extracted from this sample were yellow and purple to pale-brown. CL-images shows well-defined oscillatory zoning no recognizable core-rim relationship. Twenty five SHRIMP analyses on the centre and rims of these grains plot along a regression line that intercepts the upper Concordia at 2716 ± 5 Ma

(MSWD=1.1)(Fig. 8e). This age is similar to the ages obtained from all biotite-poor granodiorite in the Belo Horizonte and Bonfim domes and is interpreted here as the crystallisation age of this sample.

5. Summary

The potassic granitoids form a suite of extensive, mid-crustal granitoid batholiths intruded into older amphibolite-facies TTG gneisses and amphibolites. Detailed observations from two main granitoid-gneiss complexes in the study area (the Bonfim and Belo Horizonte domes) indicate that the emplacement of the potassic magmas was periodic, marked by successive batches of granitoid intrusions. The TTG gneisses were initially intruded by granitoid sheets along the steeply-dipping layering in a lit-par-lit geometry (Fig. 5b). These layer-parallel sheets were subsequently intruded by larger granitoid bodies that form the bulk of the potassic granitoid suite in the QF. Each of these granitoid phases shows distinct geometries and intrusive styles that most likely reflect a progressive change of emplacement controls during the incremental construction of the batholiths.

Observations from the Bonfim granitoid-gneiss complex show that the core of the Mamona and Souza Neschese batholiths are represented by massive granitoid bodies, which occupy the topographically higher periphery of the complex, at the contact with the overlying supracrustal rocks. In contrast, the TTG gneisses and sheeted granitoids are mainly observed in the more eroded portions (interior) of the complex. This spatial relationship suggests that the homogeneous granitoids of the batholiths are the eroded remnants of much larger horizontal sheets, which were fed by vertical m-wide granitoid sheets. Differential erosion, most likely during deposition of the overlying Minas conglomerates and sandstones (discussed below), exposed large portions of the interior of the TTG complexes.

A compilation of the respective crystallisation ages of the potassic granitoids (Table 1) indicates two consecutive stages of potassic granitoid magmatism at 2760-2750 Ma and 2730-2700 Ma, and a

substantially younger (~100 My) magmatic event at 2612-2613 Ma. The oldest granitoid bodies are represented by foliated, biotite-rich granodiorites in the Florestal and Pequi batholiths for which we have obtained U/Pb LA-ICP-MS intercept ages of 2758 ± 5 Ma and 2750 ± 13 Ma, respectively. Another two samples of this initial pulse of potassic magmatism - collected to the south of the Florestal batholith and in the northern part of the Bação dome (Fig. 2) - were dated at 2755 ± 14 Ma (ID-TIMS age data, Romano 1989) and 2744 ± 10 Ma (sample MR11, Figs. 4 and 8d).

The 2760-2750 Ma granodiorites are intruded by weakly foliated to non-foliated biotite-bearing granitoids, which can be subdivided into two distinct phases: medium-grained grey granodiorites and coarse-grained leucogranites. The grey granodiorites from the Mamona, Souza Noschese and Pequi batholiths record identical LA-ICP-MS ages of 2730 ± 8 Ma, 2730 ± 7 Ma and 2722 ± 7 Ma, respectively. The leucogranites (from the Mamona and Souza Noschese batholiths) record LA-ICP-MS ages of 2722 ± 7 Ma and 2723 ± 9 Ma. Similarly, the three granitoid sheets sampled in the Bonfim and Bação domes yielded SHRIMP ages of 2729 ± 9 , 2719 ± 5 and 2716 ± 5 Ma. All these ages overlap within error with an ID-TIMS age of 2721 ± 3 Ma, obtained by Machado and Carneiro (1992) from a leucogranite sample in the Mamona batholith (Table 1). The youngest granitoid phases in this age group are represented by the 2708 ± 7 Ma Piracema and the 2700 ± 8 Ma General Carneiro granitoids, and some minor leucogranite intrusions in the Sousa Noschese and Pequi batholiths, which were dated at 2707 ± 7 Ma and 2700 ± 8 Ma. This pulse may also include the emplacement of the Ibirité and the Santa Luzia granites in the Belo Horizonte dome, which record ID-TIMS ages of 2698 ± 18 Ma and 2712 ± 5 Ma, respectively (Chemale et al., 1993; Noce et al., 1998).

The potassic magmatism was rejuvenated with the emplacement of relatively small granitoid bodies at the southern margin of the Bonfim granitoid-gneiss complex. An age of 2613 ± 6 Ma was obtained from a strongly foliated grey granodiorite that is located near the contact with the supracrustal sequence. A similar age of 2612 ± 3 Ma was obtained from a similar body that is located a few kilometres south of the 2613 Ma granitoid (Noce et al., 1998). The connection between these younger granitoid bodies and the main 2760-2700 Ma intrusives has yet to be investigated.

In summary, the potassic magmatism in the Southern São Francisco craton was spatially extensive and involved the construction of large km-scale batholiths above mid-crustal TTG rocks (e.g., Fig. 9a, b). LA-IPM-MS and SHRIMP U-Pb ages together with previously published results of ID-TIMS age dating suggest that the main phase of potassic magmatism, which generated 99% of potassic granitoids currently dated in the QF, took place between 2755 and 2700 Ma (Fig. 5a). Although it was a long-lived event (ca. 50-60 my.), the present age data from these rocks (Table 1), suggest that the magmatism was intermittent, taking place during two magma pulses, which were individually relatively short-lived (ca. <30 my). The remaining <1 % of granitoid crust exposed in the QF are represented by the small 2612-2613 Ma granitoid bodies exposed in the southern margin of the Bonfim dome.

6. Discussion

The Southern São Francisco craton comprises one of the largest and oldest segments of Archaean basement rocks in South America. It records several episodes of 2800 to 2770 Ma tonalite to granodiorite magmatism into older (2900-3400 Ma) TTG suites and greenstone belt sequences (Fig. 9a) (Machado and Carneiro, 1992; Machado et al., 1996; Teixeira et al., 1996; Barbosa and Sabaté, 2004). Specifically for the Southern São Francisco craton, several studies have documented tectonic accretion and multiple episodes magmatism along the 2300-2000 Ma Mineiro orogenic belt (Fig. 1) (Alkmim and Marshak 1998; Noce et al., 2000, Teixeira et al., 2000, Noce et al. 2007, Ávila et al. 2010, Seixas et al. 2012). According to these studies, the far-field compressional deformation and subsequent extension along the Palaeoproterozoic orogenic belts had direct effects on the supracrustals sequences (Rio das Velhas and Minas Supergroups), with large-scale folding of the supracrustal strata and exhumation of the granitoid-complexes in the form of km-scale domes (Alkmim and Marshak, 1998). Results of Sm-Nd and U-Pb age dating of garnet and titanite from the supracrustal crystalline rocks indicate that the doming event occurred at ca. 2.09 Ma (e.g., Machado et al., 1992; Brueckner et al., 2000). However, the timing and the process

by which the Archaean crust was transformed in a cratonic unit (that sustained the deposition of large Archaean and Palaeoproterozoic supracrustal sequences) remain unconstrained.

Evidence presented here, and published U-Pb zircon data (Table 1) are all consistent with a long-lived (>50 My) potassic magmatism into older TTG granitoids between 2760 and 2700 Ma. This magmatic event gave rise to a dominant upper granitic layer within the crust (Figs. 9a, b), which remained thermally stable. Significantly, the youngest phases of the potassic granitoids crystallised synchronously with the last episode of high-grade metamorphism in the southern part of the Bomfim dome (Campos et al., 2003). We suggest that the potassic granitoids mark the end of large-scale partial melting of the São Francisco crust, and that this portion of the lithosphere remained stable in order to sustain the deposition of the platform sediments of the Minas basin. Notably, our U-Pb age dating and published TIMS ages do not indicate younger magmatic processes or high temperature metamorphic events leading to zircon overgrowth in the Proterozoic. This implies that the large-scale, upper crustal deformation and up doming of crystalline rocks at ca. 2.09 Ga (Alkmim and Marshak, 1998) was not associated with partial melting and remobilisation of the lower crust.

A number 2730 to 2700 Ma potassic granitoids have recently been observed to the north, in the central part of the Gavião block, hundreds of kilometres north of the study area (Cruz et al, 2012). U-Pb and Nd isotope data presented by Cruz et al. (2012) together with our U-Pb ages suggest that the partial melting and emplacement of potassic granitoids was extensive, probably affecting much of the Gavião block and, thus, the entire Mesoarchaeon nucleus of the São Francisco craton. Such voluminous amounts of potassic melt require an extensive mobilisation of magmas from the deep crust and, consequently, produce a chemical stratification of the crust (Fig. 9a, b). This occurs due to the fact that heat-producing elements (K, Th, U etc.) partition strongly into the granite magma (e.g., Taylor and McLennan, 1985; Thompson, 1982, 1999). The extraction of such magmas from deep crustal sources and their emplacement into the upper crust should have concentrated heat-producing elements in the upper crust, and left the lower crust thermally stable (e.g., Sandiford and McLaren, 2002; Sandiford et al., 2002; Sandiford et al., 2004). In addition, dehydration with partial melting was likely to change the bulk composition of the source, leaving the lower crust dry

(refractory) and therefore more resistant to future episodes of partial melting (Fig. 9b) (e.g., Thompson, 1982).

The link between potassic granitoid production and lower crustal dehydration is well exemplified in the central parts of the Kaapvaal craton, where exposed (granulite-facies) middle to lower crustal segments were produced during emplacement of voluminous potassic granitoids throughout the craton (Poujol et al., 2003, Schmitz et al., 2004; Armstrong et al., 2006). These include potassic granitoids exposed in the Barberton Terrain (Robb et al., 1983; Kamo and Davis 1994, Belcher and Kisters, 2006), Vredefort dome (Moser et al., 2001; Lana et al., 2003, 2004), Johannesburg dome (Anhaeusser, 1999; Poujol and Anhaeusser, 2001). Some of these granitoids (in the central and eastern parts of the craton) were quickly exhumed and eroded within millions of years after crystallisation (e.g., Lana et al., 2006, 2011; Schoene et al., 2008; 2009), indicating that much of the heat producing elements extracted from the lower crust were redistributed into the overlying sediments of the overlying intracratonic basins (i.e., Pongola and Witwatersrand Basins). As for the São Francisco craton, evidence from detrital zircon studies indicates that the potassic magmatism was shortly followed by the on-set of the Minas Supergroup deposition (Fig. 9c) (Machado et al 1996, Hartmann et al., 2006). A close inspection of the detrital U-Pb data suggests that the potassic granitoids were the main sources of Archaean zircons to the Minas Supergroup clastic sediments (Machado et al. 1996, Hartmann et al., 2006). This implies that the heat-producing elements that accumulated in the upper crust due to the potassic magmatism were likely redistributed in the supracrustal sequence, during exhumation and peneplanation of the 2750-2600 Ma granites and the deposition of the Minas Supergroup (Fig. 9c).

Therefore, field observations and U-Pb geochronological data available for the Southern São Francisco craton can be reconciled with broader crustal models in which widespread partial melting and upward migration of voluminous potassic magma generate a stratified rheological column within the lithosphere (e.g., De Wit et al., 1992; Kusky and Polat, 1999; Moser et al., 2001). This stratified crust (with an upper granitic layer and thermally stable lower crust) was, in turn, shielded from

further partial melting and pervasive ductile deformation. As proposed in these previous models (e.g., De Wit et al., 1992; De Wit, 1998; Kusky and Polak, 1999), the generation of voluminous potassic granitoids (such as those studied here) is in all likelihood associated with basalt intraplate due to partial melting in the mantle (mantle decompression). While more data is necessary for further understanding of the deep crust of the São Francisco craton, our study provides some clues to the fact that a mantle root beneath the shield existed before the 2100 Ma orogeny - including the lack of younger granitoid magmatism, the absence of thermal resetting of the magmatic and detrital zircons, and the fact that the cores of the batholiths are devoid of Proterozoic ductile deformation. We believe that the crustal melting and widespread granitic plutonism were directly associated with the establishment and stabilisation of this mantle keel between 2750 and 2700 Ma.

7. Acknowledgements

This material is based on work supported by the FAPEMIG under grant numbers FAPEMIG/VALE-RDP-00067-10 and FAPEMIG-APQ-03943-10 awarded to Cristiano Lana. SHRIMP analyses were sponsored by CNPq grant 480317/2010-0 awarded to Fernando Alkmim. Editor Randal Parish and two anonymous reviewers are greatly acknowledged for constructive reviews on this manuscript.

8. Appendix A

Zircons were extracted from the granitoids by conventional crushing, heavy liquid, and magnetic separation techniques. The grains were subsequently separated into different populations based on crystal morphology, colour, clarity and inclusion characteristics. From these populations, representative crystals were mounted in epoxy, polished, and imaged by secondary electron image and cathodoluminescence (CL) using the LEO electron microscope at the Department of Geology, Stellenbosch University. The CL and SEI imaging techniques used an accelerating voltage of 20 keV, 10 nA beam current, and a 1 μm beam diameter. The CL image was collected with a CENTAURUS CL detector (sensitive to wavelengths of 400–600 nm) mounted in place of the Backscatter detector. Some mineral inclusions were identified by energy dispersive analysis (EDS) under the same instrumental parameters.

8.1 LA-ICP-MS

In situ U–Pb LA–ICP–MS analysis was performed using an Agilent 7500ce ICP–MS and a 213 nm New Wave laser at the Department of Geosciences, University of Stellenbosch, South Africa. Operating conditions were optimised to provide maximum sensitivity for the high masses (^{207}Pb and ^{238}U) while inhibiting oxide formation ($\text{ThO}^+/\text{Th}^+ < 0.5\%$). The standard and unknown zircons were ablated in small volume (tear-drop shape) sample cell, with an insert that holds one 25-mm-diameter sample mount and a 10-mm-diameter standard mount. Acquisitions consisted of a 20 s measurement of the gas blank, followed by 40 s measurement of U, Th and Pb signals during ablation. Samples, standards and sample holders were acid-washed before being analysed to remove possible surface Pb contamination. Laser ablations were performed at 30 μm spot size, $\sim 10 \text{ J/cm}^2$ fluence and 10 Hz repetition rate. Ablations occurred in a He carrier gas, and the resulting aerosol was mixed with Ar prior to introduction into the ICP–MS via 4 mm Tygon tubing (pre-cleaned with 1% ultra-pure nitric acid). Integration times were 15 ms for ^{206}Pb ; 40 ms for ^{207}Pb and 10 ms for ^{208}Pb ; ^{204}Pb ; ^{232}Th , ^{238}U .

The relevant isotopic ratios ($^{207}\text{Pb}/^{206}\text{Pb}$, $^{208}\text{Pb}/^{206}\text{Pb}$, $^{208}\text{Pb}/^{232}\text{Th}$, $^{206}\text{Pb}/^{238}\text{U}$ and $^{207}\text{Pb}/^{235}\text{U}$, where ^{235}U was calculated from ^{238}U counts via the natural abundance ratio $^{235}\text{U} = ^{238}\text{U}/137.88$) have been calculated using the data reduction software Glitter (Van Achterbergh et al., 2001). Individual isotopic ratios were displayed in time-resolved mode. For our laser system, isotopic ratios generated during the first 10s of each analysis were discarded. The integration window for the remainder of each analysis was chosen so as to maximise concordance and to exclude signal segments that were related to zones of Pb loss (e.g. fractures), high common Pb (as recognised by ^{204}Pb counts markedly higher than the high background caused by ^{204}Hg contamination, see below) or Pb inheritance.

Ablation depth-dependent elemental fractionation was corrected for by tying the integration window for the unknown zircon to the integration window of the standard zircon GJ-1 (Jackson et al., 2004). Instrumental drift was corrected against the zircon standard using linear interpolative fits. Calibrations were based on six or more analyses of the standard (6 analyses of unknowns bracketed between 3 analyses of standards). ^{204}Pb -based common Pb corrections were not applied. Two secondary standards were used before and during runs: Plesovice zircon ($337 \pm 1 \text{ Ma}$; Slama et al., 2008) and 91500 zircon ($1064 \pm 1 \text{ Ma}$; Wiedenbeck et al., 1995). The results are within error of recommended TIMS ages. Sixty analyses of Plesovice zircon produced within the runs gave a Concordia age of $338 \pm 1 \text{ Ma}$ (mean $^{206}\text{Pb}/^{238}\text{U}$ age = 338 ± 1 ; mean $^{207}\text{Pb}/^{235}\text{U}$ age = $339 \pm 1 \text{ Ma}$). Fifteen analyses of zircon 91500 produced before the runs gave a Concordia age of $1067 \pm 5 \text{ Ma}$ (mean $^{206}\text{Pb}/^{238}\text{U}$ age = 1065 ± 5 ; mean $^{207}\text{Pb}/^{235}\text{U}$ age = $1068 \pm 5 \text{ Ma}$). Further details on the long term reproducibility can be found in Lana et al. (2011) and Buick et al. (2011).

8.2 SHRIMP

SHRIMP RG U-Th-Pb analyses were performed at the Research School of Earth Sciences at the Australian National University, Canberra. The SHRIMP operated at a mass resolution exceeding 6500 in order to eliminate all significant isobaric interferences. Positive secondary ions were ablated from areas 30 μm in diameter by a 10 kV negatively charged oxygen beam maintained at a current of 4 nA. Ion counting with a single collector was done sequentially by magnetic field stepping through Zr_2O^+ , $^{204}\text{Pb}^+$, background, $^{206}\text{Pb}^+$, $^{207}\text{Pb}^+$, $^{208}\text{Pb}^+$, $^{238}\text{U}^+$, ThO^+ and UO^+ . The data were combined after six cycles and reduced. Pb isotopic ratios are reported directly, as mass discrimination at < 0.25% per mass unit has a negligible effect for $^{207}\text{Pb}/^{206}\text{Pb}$ and Pb/U ages. Collection and reduction of the data followed methods described by Williams (1998), and references therein). Corrections for common lead were made using the measured $^{204}\text{Pb}/^{206}\text{Pb}$ ratios and the appropriate model Pb compositions from Stacey and Kramers (1975). Elemental concentrations and inter-element ratios were measured relative to a standard zircon Temora (Jackson et al., 2004). Correlated changes between Pb^+/U^+ and UO^+/U^+ during analysis were compensated using a quadratic relationship determined on the standard zircon. Reproducibility of $^{206}\text{Pb}/^{238}\text{U}$ in the standard runs was always better than 2% over the period of this study.

The LA-ICP-MS and SHRIMP data were reduced using the ISOPLOT/SQUID programs (Ludwig, 1999; 2000) with ages calculated and plotted on Concordia diagrams using the IsoplotEx 2.46 program (Ludwig, 1999; 2000). Uncertainties given for individual analyses (ratios and ages) are at the 1 σ level. All uncertainties in the calculated intercept or Concordia ages are reported at 2 σ confidence limits, unless stated otherwise. The results of the spot analyses are presented in the electronic content.

9. Appendix B Supplementary Content

Cathodoluminescence images of zircons analysed in this study. Supplementary data associated with this article can be found, in the online version, at doi:XXXX/j.precamres.XXXX.

10. Appendix C Supplementary Content

Table 1 - SHRIMP and LA-ICP-MS U-Pb data of 16 potassic granitoids samples from the southern part of the São Francisco craton. Table 2 - LA-ICP-MS U-Pb data of secondary standards run during this study. Supplementary data associated with this article can be found, in the online version, at doi:XXXX/j.precamres.XXXX.

11. References

- Alkmim, F.F. 2004. O que faz de um cráton um cráton ? O Cráton do São Francisco e as revelações Almedianas ao delimita-lo. In: Mantesso-Neto et al. (eds) *Geologia do Continente Sul-Americano. Evolução da obra de Fernando Flávio Marques de Almeida*. Becca, São Paulo, p.17-35.
- Alkmim, F.F., Marshak, S., 1998. Transamazonian orogeny in the southern São Francisco craton region, Minas Gerais, Brazil: evidence for Paleoproterozoic collision and collapse in the Quadrilátero Ferrífero. *Precambrian Research* 90, 29–58.
- Alkmim, F.F. and Noce, C.M. 2006. The Paleoproterozoic Record of the São Francisco craton. IGCP 509 Field workshop, Bahia and Minas Gerais, Brazil. *Field Guide & Abstracts*, 114 p.
- Alkmim, F.F. and Martins-Neto, M.A., 2012. Proterozoic first-order sedimentary sequences of the São Francisco craton, eastern Brazil. *Marine and Petroleum Geology*, 33, 127-139.
- Almeida, F.F.M., Hasui, Y., Brito Neves, B.B., Fuck, R.A., 1981. Brazilian structural provinces: an introduction. *Earth Sci. Rev.*, 17, 1–29.
- Almeida, F.F.M., 1981. O Cráton do Paramirim e suas relações com o do São Francisco. *Anais do Simpósio sobre o Cráton do São Francisco e suas faixas marginais*. Sociedade Brasileira de Geologia, Salvador, pp. 1-10.
- Anhaeusser, C.R., Robb, L.J., 1983. Geological and geochemical characteristics of the Heerenveen and Mpuluzi batholiths south of the Barberton greenstone belt and preliminary thoughts on their petrogenesis. In: Anhaeusser, C.R. (ed.) *Contributions to the Geology of the Barberton Mountain Land*. Special Publication of the Geological Society of South Africa, 9, 131–151.
- Anhaeusser, C.R., 1999. Archaean crustal evolution of the central parts of the Kaapvaal Craton, South Africa: Evidence from the Johannesburg dome. *S. Afr. J. Geol.* 95, 111–116.
- Armstrong, R.A., Lana, C., Reimold, W.U., Gibson, R.L., 2006. SHRIMP zircon age constraints on Mesoarchean crustal development in the Vredefort dome, central Kaapvaal craton, South Africa, in Reimold, W.U. and Gibson, R.L., *Processes on the Early Earth: Geological Society of America Special Paper 405*, p. 233-253.
- Ávila, A., Teixeira, W., Cordani, U.G., Moura, C.A.V., Pereira, R.M., 2010. Rhyacian (2.23–2.20 Ga) juvenile accretion in the southern São Francisco craton, Brazil: geochemical and isotopic evidence

- from the Serrinha magmatic suite, Mineiro belt Journal of South American Earth Sciences, 29, 464–482
- Babinski, M., Chemale, F., Van Schumus, W.R., 1995. The Pb/Pb age of the Minas Supergroup carbonate rocks, Quadrilátero Ferrífero, Brazil. *Precambrian Research*, 72, 235-245
- Barbosa, J.S.F., Sabaté, P. 2004. Archean and Paleoproterozoic crust of the São Francisco Cráton, Bahia, Brazil: geodynamic features. *Precambrian Research*, 133, 1-27.
- Belcher, R, and Kisters, A F.M., 2006. Syntectonic emplacement and deformation of the Heerenveen batholith: Conjectures on the structural setting of the 3.1 Ga granite magmatism in the Barberton granite-greenstone terrain, South Africa. *Geological Society of America Special Papers*, 405, 211-231.
- Buick, I.S., Lana, C., & Gregory, C. 2011. A LA-ICP-MS and SHRIMP U/Pb age constraint on the timing of REE mineralisation associated with Bushveld granites. *South African Journal of Geology*, 144, 1-14.
- Campos, J. C. S.; Carneiro, M. A.; Basei, M. A. S., 2003. U-Pb evidence for Late Neoproterozoic crustal reworking in southern São Francisco Craton (Minas Gerais, Brazil). *Anais da Academia Brasileira de Ciências* 75, 497-511.
- Carneiro, M.A., 1992. O Complexo Metamórfico Bonfim Setentrional (Quadrilátero Ferrífero, Minas Gerais): Litoestratigrafia e evolução geológica de um segmento de crosta continental do Arqueano. Unpublished PhD Thesis, University of São Paulo, Brazil, 233p.
- Carneiro, M.A., Jord-Evangelista, H., Teixeira, W., 1997 Eventos magmáticos arqueanos de natureza cálcio-alcalina e thoiítica no Quadrilátero Ferrífero e suas implicações tectônicas. *Revista Brasileira de Geociências* 27, 121-128
- Chemale, F.; Babinski, M.; Van Schmus, W.R., 1993. U/Pb dating of granitic-gneissic rocks from the Belo Horizonte and Bonfim complexes, Quadrilátero Ferrífero (Brazil). Report for CNPq and NSF-EAR Project on São Francisco Cráton Margin Transect Project, 16p.
- Cruz, S.C.P.; Peucat, J-J.; Teixeira, L.; Carneiro, M.A.; Martins, A.A.M.; Santana, J.S.; Souza, J.S., Barbosa, J.S.F.; Leal, A.B.M.; Dantas, E.; Pimentel, M. 2012. The Caraguataí syenitic suite, a ca 2.7 Ga-old alkaline agmatism (petrology, geochemistry and U-Pb zircon ages). Southern Gavião block (São Francisco Craton), Brazil. *Journal of South American Earth Sciences*, 37, 1-18.

- De Ronde, C.E.J., De Wit, M.J., 1994. Tectonic history of the Barberton greenstone belt, South Africa: 490 million years of Archean crustal evolution. *Tectonics* 13, 983-1005.
- De Wit, M.J., 1998. On Archaean granites, greenstones, cratons and tectonics: does the evidence demand a verdict? *Precambrian Research* 91, 181–226.
- De Wit, M.J., Roering, C., Hart, R.J., Armstrong, R.A., de Ronde, C.E.J., Green, R.W.E., Tredoux, M., Peberdy, E., Hart, R.A., 1992. Formation of an Archaean continent. *Nature* 357, 553–562.
- Dirks, P.H.G.M., Jelsma, H.A., 1998. Horizontal accretion leading to stabilization on the Archean Zimbabwe Craton. *Geology* 26, 11-14.
- Dorr Il, J.V.N., Gair, J.E., Pomerene, J.B., Rynearson, G.A., 1957. Revisão da estratigrafia precambriana do Quadrilátero Ferrífero, Brasil. DNPM-DFPM. Avulso 81, 1–31.
- Dorr Il, J.V.N., 1969. Physiographic, stratigraphic and structural development of the Quadrilátero Ferrífero, Minas Gerais, Brazil. U.S. Geological Survey, Professional Paper 641-A, 1–110.
- Drüppel, K., McCready, A.J., Stumpf, E.F., 2009. High-K granites of the Rum Jungle Complex, N-Australia: Insights into the Late Archean crustal evolution of the North Australian Craton. *Lithos* 111, 203-219.
- Gair, J.E., 1962. Geology and ore deposits of the Nova Lima and Rio Acima quadrangles, Minas Gerais, Brazil. U.S. Geological Survey, Professional Paper 341-A, 1–67.
- Hartmann, L.A., Endo, I., Suita, M.D.F., Santos, J.O.S., Frantz, J.C., Carneiro, M.A., McNaughton, N.J., Barley, M.E., 2006. Provenance and age delimitation of Quadrilátero Ferrífero sandstones based on zircon U-Pb isotopes. *Journal of South American Earth Sciences* 20, 273–285.
- Herz, N. 1970. Gneissic and igneous rocks of the Quadrilátero Ferrífero, Minas Gerais, Brazil. U.S. Geological Survey Professional Paper, 641-B, pp. B1-B58.
- Herz, N. 1978. Metamorphic rocks of the Quadrilátero Ferrífero, Minas Gerais, Brazil. U.S. Geological Survey Professional Paper, 641-C, pp. C1-C81.
- Jackson, S.E., Pearson, N.J., Griffin, W.L., Belousova, E.A., 2004. The application of laser ablation-inductively coupled plasma-mass spectrometry to in situ U–Pb zircon geochronology. *Chemical*

- 870 Geology, 211, 47–69.
- 871
- 872 Jayananda, M., Chardon, D., Peucat, J.-J., Capdevila, R., 2006. 2.61 Ga potassic granites and
 873 crustal reworking in the western Dharwar craton, southern India: tectonic, geochronologic and
 874 geochemical constraints. *Precambrian Research* 150, 1–26.
- 875
- 876 Kamo, S.L., Davis, D.W., 1994. Reassessment of Archaean crustal development in the Barberton
 877 Mountain Land, South Africa, based on U–Pb dating. *Tectonics* 13 (1), 167–192.
- 878
- 879 Kusky, T.M., 1993. Collapse of Archean orogens and the generation of late-to post-kinematic
 880 granitoids. *Geology* 21, 925–928.
- 881
- 882 Kusky, T.M., Polat, A., 1999. Growth of granite–greenstone terranes at convergent margins, and
 883 stabilization of Archean cratons. *Tectonophysics* 305, 43–73.
- 884
- 885 Lana, C., Gibson, R.L., Kisters, A., and Reimold, W.U., 2003. Archean crustal structure of the
 886 Kaapvaal craton, South Africa—Evidence from the Vredefort dome: *Earth and Planetary Science*
 887 *Letters*, v. 206, p. 133–144, doi: 10.1016/S0012-821X(02)01086-5.
- 888
- 889 Lana, C., Reimold, W.U., Gibson, R.L., Koeberl, C., and Siegesmund, S., 2004. Nature of the
 890 Archean mid-crust in the core of the Vredefort dome, Central Kaapvaal Craton, South Africa:
 891 *Geochimica et Cosmochimica Acta*, v. 68, p. 623–642, doi: 10.1016/S0016-7037(03)00447-2.
- 892
- 893 Lana, C., Gibson, R.L., Reimold, W.U., and Minnitt, R.A.M., 2006. The Broodkop Shear Zone,
 894 southeastern Vredefort dome, South Africa; a Dominion-related extensional feature?: *South African*
 895 *Journal of Geology*, v. 109, p. 265–278.
- 896
- 897 Lana, C., Buick, I., Stevens, G., Rossouw, R. & De Wet, W. 2011. 3230–3200 Ma post-orogenic
 898 extension and mid-crustal magmatism along the southeastern margin of the Barberton Greenstone
 899 Belt, South Africa. *Journal of Structural Geology* 33, 844–858.
- 900
- 901 Ladeira, E.A., 1980. Metallogenesis of gold at the Morro Velho Mine, and in the Nova Lima District,
 902 Quadrilátero Ferrífero, Minas Gerais, Brazil. Unpublished Ph.D. thesis, University of Western
 903 Ontario, Canada, 272p.
- 904
- 905 Ladeira, E.A., 1981. Primeiras lavas com almofadas (pillows) encontradas no Supergupo Rio das
 906 Velhas, de idades Arqueana, no Quadrilátero Ferrífero e no Distrito de Pitangui, Minas Gerais.
 907 *Ciencias da Terra* 1, 12–14.

- Ledru, P., Johan, V. Milesi, J.P., Tegye, M. J. 1994. Evidence for a 2 Ga continental accretion in the circum-south Atlantic provinces. *Precambrian Research*, 69, 169-171
- Ludwig, K.R., 1999. Isoplot/Ex version 2.00: A Geochronological Toolkit for Microsoft Excel, vol. 1a. Berkeley Geochronological Center Spec. Publ, 46 pp.
- Ludwig, K.R., 2000. SQUID 1.00, A User's Manual, vol. 2. Berkeley Geochronology Center Spec. Publ, 17 pp.
- Machado, N., Carneiro, M.A., 1992. U-Pb evidence of late Archean tectono-thermal activity in the southern São Francisco shield, Brazil. *Canadian Journal of Earth Sciences* 29, 2341-2346.
- Machado, N., Noce, C.M., Ladeira, E.A., Belo de Oliveira, O.A. 1992. U-Pb geochronology of Archean magmatism and Proterozoic metamorphism in the Quadrilátero Ferrífero, Southern São Francisco Craton, Brazil. *Geological Society of America Bulletin* 104, 1221-1227.
- Machado, N., Schrank, A., Noce, C.M., Gauthier, G. 1996. Ages of detrital zircon from Archean-Paleoproterozoic sequences: Implications for Greenstone Belt setting and evolution of a Transamazonian foreland basin in Quadrilátero Ferrífero, southeast Brazil. *Earth and Planetary Science Letters* 141, 259-276.
- Marshak, S., Alkmim F.F., Jordt-Evangelista, H., 1992. Proterozoic crustal extension and the generation of dome-and-keel structures in an Archaean granite-greenstone terrane. *Nature* 357, 491-493.
- Moser, D.E., Heaman, L.M., Krogh, T.E., and Hanes, J.A., 1996. Intracrustal extension of an Archean orogen revealed using single-grain U-Pb zircon geochronology: *Tectonics*, v. 15, p. 1093–1109.
- Moser, D.E., Flowers, R.M., Hart, R.J., 2001. Birth of the Kaapvaal tectosphere 3.08 billion years ago, *Science* 291. 465-468.
- Noce, C.M. 1995. Geocronologia dos eventos magmáticos, sedimentares e metamórficos na região do Quadrilátero Ferrífero, Minas Gerais. Unpublished PhD Theses, University of São Paulo, Brazil, 129 p.

- Noce, C.M., Teixeira, W., Machado, N., 1997. Geoquímica dos gnaisses TTG e granitóides neoarqueanos do Complexo Belo Horizonte, Quadrilátero Ferrífero, Minas Gerais. *Revista Brasileira de Geociências* 27, 25-32.
- Noce, C.M., Machado, N., Teixeira, W., 1998. U-Pb geochronology of gneisses and granitoids in the Quadrilátero Ferrífero (southern São Francisco craton): age constraints for Archean and Paleoproterozoic magmatism and metamorphism. *Revista Brasileira de Geociências* 28, 95-102
- Noce, C.M., Teixeira, W., Quemeneur, J.J.G., Martins, V.T.S., Bolzachini, E., 2000. Isotopic signatures of paleoproterozoic granitoids from the southern São Francisco Craton and implications for the evolution of the transamazonian orogeny. *Journal of South American Earth Sciences* 13, 225–239.
- Noce, C.M., Zuccheti, M., Baltazar, O.F., Armstrong, R., Dantas, E., Renger, F.E., Lobato, L.M., 2005. Age of felsic volcanism and the role of ancient continental crust in the evolution of the Neoproterozoic Rio das Velhas Greenstone belt (Quadrilátero Ferrífero, Brazil): U–Pb zircon dating of volcanoclastic graywackes. *Precambrian Research* 141, 67–82.
- Noce, C.M., Pedrosa-Soares, A.C., Silva, L.C., Armstrong, R., Piuzana, D., 2007. Evolution of polycyclic basement complexes in the Araçuaí Orogen, based on U–Pb SHRIMP data: Implications for Brazil–Africa links in Paleoproterozoic time. *Precambrian Research*, 159, 60-78.
- O'Rourke, J.E., 1957. The stratigraphy of metamorphic rocks of the Rio de Pedras and Gandarela quadrangles, Minas Gerais, Brazil. Unpublished Ph.D. thesis, University of Wisconsin, USA, 106p.
- Poujol, M., Robb, L.J., Anhaeusser, C.R., Gericke, B., 2003. A review of the geochronological constraints on the evolution of the Kaapvaal Craton, South Africa. *Precambrian Research* 127, 181–213.
- Poujol, M., Anhaeusser, C.R., 2001. The Johannesburg Dome, South Africa: new single zircon U–Pb isotopic evidence for early Archean granite–greenstone development within the central Kaapvaal Craton. *Precambrian Res.* 108, 139–157.
- Renger, F. E., Noce, C.M., Romano, A.W. and Machado, N., 1995. Evolução sedimentar do Supergrupo Minas: 500 Ma. de registro geológico no Quadrilátero Ferrífero, Minas Gerais, Brasil. *Geonomos* 2, 1-11.

Robb, L.J., Anhaeusser, C.R. and Van Nierop, D.A., 1983. The recognition of the Nelspruit batholith north of the Barberton greenstone belt and its significance in terms of Archaean crustal evolution. In: Anhaeusser, C.R. (ed.) Contributions to the Geology of the Barberton Mountain Land. Special Publication of the Geological Society of South Africa 9, 117–130.

Romano, A.W. 1989. Evolution tectonique de la région NW du Quadrilatère Ferrifère - Minas Gerais, Brésil. Unpublished PhD Thesis, University of Nancy, France, 259p.

Reis, L.A., Martins-Neto, M.A., Gomes, N.S., Endo, I., 2002. A bacia de antepaís paleoproterozóica Sabará, Quadrilátero Ferrífero, MG. Revista Brasileira de Geociências 32, 43-58.

Sandiford, M., McLaren, S., 2002. Tectonic feedback and the ordering of heat producing elements within the continental lithosphere. Earth Planetary Science Letters 204, 133-150.

Sandiford, M., McLaren, S., Neumann, N., 2002. Long-term thermal consequences of the redistribution of heat-producing elements associated with large-scale granitic complexes, J. Metamorphic Geology 20, 87-98.

Sandiford, M., Van Kranendonk, M. J., and Bodorkos, S., 2004. Conductive incubation and the origin of dome-and-keel structure in Archean granite-greenstone terrains: A model based on the eastern Pilbara Craton, Western Australia, Tectonics, 23.

Schmitz, M.D., Bowring, S.A., de Wit, M.J. and Gartz, V., 2004. Subduction and terrane collision stabilized the western Kaapvaal craton tectosphere 2.9 billion years ago. Earth Planet. Sci. Lett. 222, 363–376.

Seixas, L.A.R., David, J., Stevenson, R., 2012. Geochemistry, Nd isotopes and U–Pb geochronology of a 2350 Ma TTG suite, Minas Gerais, Brazil: Implications for the crustal evolution of the southern São Francisco craton. Precambrian Research 196, 61-80.

Sláma, J., Košler, J., Condon, D.J., Crowley, J.L., Gerdes, A., Hanchar, J.M., Horstwood, M.S. A., Morris, G.A., Nasdala, L., Norberg, N., Schaltegger, U., Schoene, B., Tubrett, M.N., Whitehouse, M.J., 2008. Plešovice zircon—a new natural reference material for U–Pb and Hf isotopic microanalysis. Chemical Geology 249, 1–35.

Schoene, B., De Wit, M.J., Bowring, S.A., 2008. MesoArchaean assembly and stabilization of the eastern Kaapvaal craton. A structural-thermochronological perspective. Tectonics 27, 1-27.

- Schoene, B., Duda, F.O., De Wit, M.J., Bowring, S.A., 2009. Sm-Nd isotopic mapping of lithospheric growth and stabilization in the eastern Kaapvaal craton. *Terra Nova* 21, 219-228.
- Sylvester, P.J., 1994. Archean granite plutons. In: Condie, K.C. (Ed.), *Archean Crustal Evolution. Developments in Precambrian Geology*, vol. 11. Elsevier, Amsterdam, pp. 261-314.
- Stacey, J.S., Kramers, J.D., 1975. Approximation of terrestrial lead isotope evolution by a two stage model. *Earth Planetary Science Letters* 26, 207-221.
- Teixeira, W. and Figueiredo, M.C.H., 1991. An outline of Early Proterozoic crustal evolution in the São Francisco craton, Brazil: a review. *Precambrian Res.*, 53(1-2): 1-22.
- Teixeira, W., Carneiro, M.A., Noce, C.A., Machado, N., Sato, K., Taylor, P.N., 1996. Pb, Sr and Nd isotope constraints on the archaean evolution of gneissic granitoid complexes in the southern São Francisco craton, Brazil. *Precambrian Research* 78, 151-164.
- Teixeira, W., Sabaté, P., Barbosa, J.S.F., Noce, C.M. and Carneiro, M.A. 2000. Archean and Paleoproterozoic Tectonic evolution of the São Francisco Craton, Brazil. In: Cordani, U.G., Milani, E.J., Thomas Filho, A. And Campos, D.A. (Eds.), *Tectonic Evolution of the South America. International Geologic Congress 31, Rio de Janeiro, Brazil*, p. 101-137
- Thompson, A. B. 1982. Dehydration melting of pelitic rocks and the generation of H₂O-undersaturated granitic liquids. *American Journal of Science* 282, 1567-95.
- Thompson, A. B. 1999. Some time-space relationships for crustal melting and granitic intrusion at various depths. In Castro, A., Fernandez, C. & Vigneresse, J. L. (eds) *Understanding Granites: Integrating New and Classical Techniques*. Geological Society, London, Special Publication 168, 7-25. London: Geological Society.
- Taylor, S.R., McLennan, S.M., 1985. *The Continental Crust: Its Composition and Evolution*, 312. Blackwell Scientific, Oxford.
- Van Achterbergh, E., Ryan, C.G., Jackson, S.E., Griffin, W.L., 2001. Data reduction software for LA-ICP-MS: appendix. In: P.J. Sylvester, Editor, *Laser Ablation-ICP-Mass Spectrometry in the Earth Sciences: Principles and Applications*, Mineralog. Assoc. Canada (MAC) Short Course Series, Ottawa, Ontario, Canada vol. 29 (2001), pp. 239-243.

Wells, P.R.A., 1981. Accretion of continental crust: thermal and geochemical consequences. *Phil. Trans. R. Soc. Lond. A301*, 347–357.

Wiedenbeck, M., Allé, P., Corfu, F., Griffin, W.L., Meier, M., Oberli, F., von Quadt, A., Roddick, J.C., Spiegel, W., 1995. Three natural zircon standards for U–Th–Pb, Lu–Hf, trace element and REE analyses. *Geostandards Newsletters* 19, 1–23.

Williams, I.S., 1998. U–Th–Pb geochronology by ion microprobe. In: McKibben, M.A., Shanks III, W.C., Ridley, W.I. (Eds.), *Applications of Microanalytical Techniques to Understanding Mineralizing Processes*. *Rev. Econ. Geol.*, vol. 7, pp. 1–35.

Zucchetti, M., Baltazar, O.F., Raposo, F.O. (Eds) 1998. *Projeto Rio das Velhas – Texto Explicativo do Mapa Geológico Integrado, Escala 1:100.000*. DNPM/CPRM Serviço Geológico do Brasil, 157p.

Figure 1: Sketch map of the southern tip of the São Francisco craton showing the main Archaean terrain and the surrounding Archaean/Palaeoproterozoic basement rocks reworked in the Proterozoic (the Mineiro and Araçuaí orogenic belt, respectively, to the south and east of the QF) (modified from Alkmim, 2004 and Alkmim and Noce, 2006).

Figure 2: Geological map of the Quadrilátero Ferrífero and surrounding granitoids of the southern part of the São Francisco craton. Note that the eastern and southeastern margins of the Quadrilátero Ferrífero are bounded by Archaean basement and supratratal rocks reworked at ca. 2100 and 570 Ma. Previously published U–Pb ages of some relevant granitoid rocks are indicated.

Figure 3: Stratigraphic column of the supracrustal sequences in Quadrilátero Ferrífero district (based on Dorr, 1969 and Alkmim and Marshak, 1998). The references to the age data are as indicated in the figure: (1) Machado et al. (1996), (2) Hartmann et al. (2006), (3) Noce et al. (2005), (4) Machado and Carneiro (1992), (5) Machado et al. (1992), (6) Noce et al. (1998), (7) Babinski et al. (1995).

Figure 4: a) Geological map of the study area showing the main potassic granitoids and the U–Pb LA–ICP–MS ages obtained in this study. b) Schematic cross section through the granitoid–supracrustal contact in the northern edge of the Bonfim complex. Note that the massive granitoid sheet of the Souza Neschese batholith is only preserved in topographically higher areas of the Bonfim complex, near the contact with the supracrustal strata.

Figure 5: a) Image of a TTG gneisses intruded showing typical compositional banding (Bonfim dome). b) TTG gneiss intruded by foliation-parallel leucogranitoid sheets (Belo Horizonte dome). c) Potassic granitoid (Florestal batholith) containing m-scale xenoliths of folded TTG gneisses (black arrows). d) Examples of the three main phases of potassic granitoids studied here (photograph from the Pequi batholith). This includes a biotite-rich granodiorite (i), a plagioclase-quartz-biotite granodiorite (ii) and a leucogranite (iii). e) Multiple phases of leucogranites intruded into a massive biotite-rich granodiorite. f) Massive (non-foliated) granodiorite in the core of the Mamona batholith. g) Undeformed pinkish syenogranite containing m-scale xenoliths of sheeted TTG gneisses (Piracema Granitoid). h) Undeformed leucogranite from the Sousa Noschese batholith.

Fig. 6: U-Pb Concordia diagrams of LA-ICP-MS analyses of zircons from potassic granitoids in the Belo Horizonte dome (see Fig 4 for sample locality).

Figure 7: U-Pb Concordia diagrams of LA-ICP-MS analyses of zircons from potassic granitoids in the Bonfim dome (see Fig 4 for sample locality).

Figure 8: U-Pb Concordia diagrams of LA-ICP-MS analyses of zircons from potassic granitoids in the Bação e Bonfim domes (see Fig 4 for sample locality).

Figure 9: Schematic evolution of the southern part of the São Francisco Craton in the Neoarchaeon. a) Undifferentiated TTG/Greenstone crust recording concomitant deposition of the Rio das Velhas Group and emplacement of the younger TTG suites at ca. 2780-2770 Ma. b) Emplacement of potassic granitoids at 2760-2700 Ma, the deformation of Rio das Velhas Supergroup. This process led to differentiation of the crust into a refractory lower crust and an upper crust enriched in heat producing elements HPE. c) Subsequent redistribution of the HPE during erosion of the upper crust and accumulation of the Minas Supergroup clastic sediments.

Table 1: Summary of the LA-IPM-MS U-Pb dating of potassic granitoids in the Quadrilátero Ferrífero							
Batholith	Sample	Granitoid	Structure	Age (Ma)	MSWD	Method	Reference
Pulse 1							
Florestal	MR234A	Grey granodiorite	Weakly foliated	2755±8	1.0	LA-ICP-MS	This study
Pequi	MR231A	Grey granodiorite	Weakly foliated	2750±13*	0.5	LA-ICP-MS	This study
Baço granitoid body	MR11	Grey granodiorite	Foliated	2744±10*	1.4	SHRIMP	This study
Florestal		Grey granodiorite	Foliated	2755±14*		TIMS	Romano (1989)
Pulse 2							
Mamona	MR14A	Grey granodiorite	Non foliated	2730±7	1.2	LA-ICP-MS	This study
S Noshese	MR22A	Grey granodiorite	Foliated	2730±8	0.8	LA-ICP-MS	This study
Bomfim Sheet	MR10C	Bomfim granodiorite	Foliated	2729±9*	0.5	SHRIMP	This study
Mamona	MR70A	Leucogranite	Non foliated	2723±7	1.3	LA-ICP-MS	This study
S Noshese	MR148A	Milky-white leucogranite	Non foliated	2722±9	0.6	LA-ICP-MS	This study
Pequi	MR259A	Grey granodiorite	Weakly foliated	2722±7	0.9	LA-ICP-MS	This study
Mamona		Leucogranite	Weakly foliated	2721±3*		TIMS	Machado et al. (1992)
Bomfim granitoid body	MR10A	Bomfim granite	Non foliated	2719±5*	1.4	SHRIMP	This study
Bacao Sheet	MR01	Baço granite	Weakly foliated	2716±5*	1.1	SHRIMP	This study
Santa Luzia		Leucogranite	Non foliated	2712±5*		TIMS	Noce et al. (1998)
Piracema	MR137A	Pink leucogranite	Non foliated	2708 ±7	1.3	LA-ICP-MS	This study
Pequi	MR257A	Leucogranite	Non foliated	2706±7	0.7	LA-ICP-MS	This study
G Carneiro	MR51A	Milky-white leucogranite	Non foliated	2700±8	1.0	LA-ICP-MS	This study
S Noshese	MR31A	Milky-white leucogranite	Non foliated	2700±8	1.2	LA-ICP-MS	This study
Ibirite		Leucogranite	Non foliated	2698±18*		TIMS	Chemalle et al. (1993)
Younger magmatic event							
Mamona	MR87A	Grey granodiorite	Foliated	2613±6	0.4	LA-ICP-MS	This study
Mamona		Grey granodiorite	Foliated	2612±3*		TIMS	Noce et al. (1998)
*intercept age							
all other ages are Concordia ages							

Figure 1

Figure 2

Figure 3

Figure 9

a

b

c