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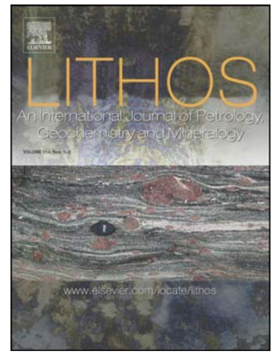

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New U-Pb SHRIMP-II zircon intrusion ages of the Cana Brava and Barro Alto layered complexes, central Brazil: constraints on the genesis and evolution of the Tonian Goias Stratiform Complex.

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Abstract

The Cana Brava, Niquelândia and Barro Alto complexes (Goiás, central Brazil) are three of the largest mafic-ultramafic layered complexes in the world and their origin has been a matter of debate for several decades. One hypothesis suggests that Niquelândia and Barro Alto were both formed by two distinct igneous events at 1.3 Ga and at 790 Ma and were later overlapped during tectonic exhumation at 650 Ma; according to this reconstruction Cana Brava belongs to the youngest intrusion at 790 Ma. A second hypothesis suggests that the three complexes formed during the same event. Here we provide new U-Pb SHRIMP-II zircon ages for the Cana Brava and Barro Alto complexes, constraining their intrusion age to the Neoproterozoic (between 770-800 Ma), coeval with Niquelândia. A review of new and literature ages indicate that these complexes formed during a single igneous event and were not modified by regional metamorphism. We propose that the complexes represent fragments of the larger Tonian Goiás Stratiform Complex**,** which was likely

part of a back-arc environment connected to the formation of the Goiás Magmatic Arc at about 790 Ma, later disrupted and accreted to the São Francisco craton.

Keywords

layered complex; U-Pb; zircon; Tonian age; Goias; Brasil

Introduction

Barro Alto, Niquelândia and Cana Brava are three mafic-ultramafic layered complexes, which outcrop in a 350 km NNE trend alignment within the Brasilia Belt in the northern Goiás (central Brazil). They share several field, stratigraphic, geochemical and geochronological features that led to their interpretation as a cogenetic and coeval large intrusion (Ferreira Filho et al., 1998; Carminatti, 2006; Giovanardi et al., 2016). In contrast, several authors claim that Barro Alto and Niquelândia were both formed by two different intrusive events (a Meso- and a Neo- Proterozoic intrusion, with Cana Brava belonging to the Neoproterozoic event; Pimentel et al., 2004, 2006; Ferreira Filho et al., 2010; Della Giustina et al., 2011). According to this two-intrusions model, the Mesoproterozoic (~1.3 Ga) anorthositic upper units of Niquelândia and Barro Alto (formerly called, by these authors, the Serra das Borges and Serra da Malacacheta complexes) were emplaced in a continental rift setting during the formation of the upper metavolcanic-metasedimentary sequences of Indaianopólis and Juscelândia. The ultramafic and gabbroic lower units of Niquelândia and Barro Alto, along with Cana Brava, were instead emplaced during a later Neoproterozoic (~800 Ma) intrusion stage. The complexes were later metamorphosed during their accretion to the São Francisco craton (Pimentel et al., 2004, 2006; Moraes et al., 2006; Ferreira Filho et al., 2010; Della Giustina et al., 2011).

Another model, based on zircon geochronology and petrological modelling of Niquelândia, suggests that the anorthosites were formed by fractionation of a plagioclase-rich crystal mush during the formation of the ultramafic units (Correia et al., 2007, 2012; Rivalenti et al., 2008). This is the so-called one-intrusion model. Moreover, a careful inspection of Niquelândia and Cana Brava suggest that no high-grade metamorphism occurred and the superimposed foliation was due to hyper-to-sub- solidus deformation during the intrusive accretion of the complexes (Correia et al., 2012; Giovanardi et al., 2016).

Here, we present new U-Pb SHRIMP-II data on zircons from the Barro Alto and Cana Brava complexes to finally constrain their age and model of formation (one- versus two-intrusions). We studied four samples (three gabbros and one diorite) from Cana Brava, being the least studied among the three complexes and with poor intrusion ages, and two samples (one gabbro from the lower units and one anorthosite from the upper units) from Barro Alto. We carefully reviewed the geochronology and stratigraphy of both complexes and compared them with those of Niquelândia. We comprehensively discuss the one-intrusion model that best fits our data and the possible former existence of the Tonian Goiás Stratiform Complex (according to the new International Chronostratigraphic Chart, v2016/04; Cohen et al., 2013; Shield-Zhou et al., 2016), whose disruption might have originated the three mafic-ultramafic complexes.

Geological setting

The Barro Alto, Niquelândia and Cana Brava layered mafic-ultramafic intrusive complexes outcrop in the Goiás state (central Brazil). They form a c.a. 350 km belt with NNE direction within the Brasilia Belt (Fig. 1) and are considered part of the Goiás Massif. This is an exotic terrane, or microcontinent, disrupted and accreted to the São Francisco craton during the Neoproterozoic Brasiliano/Panafrican event that led to the formation of the Gondwana supercontinent (Brito Neves and Cordani, 1991; Pimentel and Fuck, 1992; Fuck et al., 1994; Pimentel et al., 2000).

The three complexes overthrust to the E the rocks of the Rio Maranhão Thrust Zone, whereas to the W they exhibit intrusive contacts with the metamorphic volcano-sedimentary sequences of Palmeirópolis, Indaianópolis and Juscelândia, respectively (Figs. 2, 3 and 4).

Over the years, several names and stratigraphic subdivisions have been attributed to the three Goiás complexes (Girardi and Kurat, 1982; Girardi et al., 1986; Ferreira Filho et al., 1994; Correia and Girardi, 1998; Ferreira Filho et al., 2010; Giovanardi et al., 2015). A review of their literature names and subdivisions is reported in Table 1. Each stratigraphy begins with a basal gabbroic unit followed by one (or more) ultramafic unit and one (or more) mafic gabbroic unit. Above the latter, in Niquelândia and Barro Alto a gabbroic-anorthositic unit and a roof unit outcrop, which are alternatively considered as part of the complexes (one-intrusion model) or different intrusives (two-intrusions model).

A first attempt to simplify the stratigraphy of the three complexes was recently made based on the two-intrusions model (Ferreira Filho et al., 2010), which suggests that the complexes are formed by Meso- and Neoproterozoic intrusive events which have crystallized the upper and the lower parts of the complexes. This attempt has unified the names of the lower units of the complexes and differentiated the upper units as different intrusive. Conversely, according to the one-intrusion model (which suggests that complexes were formed during a single Neoproterozoic event), the Niquelândia complex is divided in a Lower Sequence (LS hereafter) and an Upper Sequence (US hereafter) with several sub units (Correia et al., 2007, 2012; Rivalenti et al., 2008). In this work, we revisit the classification of Ferreira Filho et al. (2010) for the lower units and the model of Correia et al. (2007, 2012) and Rivalenti et al. (2008) for the upper units and propose a new unified terminology as discussed throughout the paper.

Field observations from Barro Alto

In contrast to Niquelândia and Cana Brava and according to Ferreira Filho et al. (2010 and references therein) the stratigraphy of Barro Alto does not comprise ultramafic rocks between the lower and upper gabbroic units. Therefore, the gabbroic rocks outcropping in the Barro Alto complex have been always ascribed to the basal gabbroic unit (Ferreira Filho et al., 2010; Della Giustina et al., 2011). However, during our recent fieldwork, excavation for the enlargement of highway GO338 near the city of Goianesia, has exposed levels of ultramafic rocks in the lower gabbroic sequence of Barro Alto (Fig. 5). Some small outcrops of ultramafic rocks have also been recognized in the lower part of the stratigraphic succession in the oblique segment of the Barro Alto, although the development of sugar cane crops in the region and the consequent dismantling of all outcrops have hampered mapping the dimensions, continuity and features of the stratigraphy in the lower part of the complex. These findings suggest that, at least in the E-W trending portion of the complex, the stratigraphy of Barro Alto is similar to the one of Cana Brava.

This observation is supported also by rock features in the central and upper part of the stratigraphic succession (where the outcrops are more abundant), which are similar to the rocks of the upper gabbroic sequence of Niquelândia and Cana Brava complexes. In particular, the occurrence of magmatic amphibole and xenoliths are typical of gabbros in the upper gabbroic sequence (Rivalenti et al., 2008; Correia et al., 2012; Giovanardi et al., 2016). Magmatic amphibole has been recognized in the rocks of the central and upper stratigraphic sequence of the E-W trending part of Barro Alto, as well as xenoliths (Fig. 5).

New unified stratigraphy

According to our new stratigraphic evidence of Barro Alto, we assert the close similarity among the three complexes. Therefore, starting from the E, the LS of the Barro Alto, Niquelândia and Cana Brava complexes is composed by the following units (Figs. 2, 3 and 4):

i) Lower Mafic Zone (LMZ), formed by gabbros mainly recrystallized in micro and mylonitic textures and/or epidote-bearing amphibolites. The recrystallization of this unit is commonly recognized as the consequence of tectonic emplacement of the complexes over the Rio Maranhão Thrust Zone, which also favoured a pervasive percolation of fluids in the lower units (Girardi et al., 1986; Correia and Girardi, 1998; Correia et al., 1999; Biondi, 2014).

ii) Ultramafic Zone (UZ), formed by serpentinites interlayered with amphibolites and subordinated gabbros and pyroxenites. Serpentinites and amphibolites originated from the percolation of fluid within peridotites (serpentinites) and pyroxenites and gabbros (amphibolites). Primary cumulus textures are commonly preserved in these rocks. Approaching the top of the unit, the recrystallization decreases and pyroxenites become predominant. The top of the unit consists of pyroxenites (mainly websterites and subordinate orthopyroxenites) interlayered with gabbros. The transition to the upper unit is characterized by an increase of gabbros and decrease of abundance of pyroxenite layers.

iii) Mafic Zone (MZ), formed by gabbros, gabbro-norites and norites. Amphibole abundance increases discontinuously along the stratigraphic succession, reaching its maximum at the top of this unit (named by Girardi et al., 1986, as the 'Hydrous Zone' in Niquelândia). Together with amphibole, the rocks at the top are characterized by the occurrence of biotite. Discontinuous outcrops of diorites, sometimes containing garnet, occur in the sequence. Xenoliths embedded from the upper metavolcanic-metasedimentary sequence start also to appear in this unit. The first xenolith occurrence consists of decametres-long quartzite layers parallel to the foliation of the complexes, recognized in both Niquelândia and Cana Brava. Along the stratigraphic succession, xenoliths diminish their dimensions and lithologically are amphibolites, garnet-bearing amphibolites, gneisses, metapelite and calc-silicate rocks. Xenoliths maximum abundance is at the top of the MZ, in the Hydrous Zone (Correia et al., 2012; Giovanardi et al., 2016).

The LS is common to all complexes, whereas the US outcrops only in Niquelândia and in the northern N-S sector of Barro Alto. Cana Brava and the southern E-W segment of Barro Alto end with the MZ, which, in both complexes, show intrusive contact with the upper metavolcanic-metasedimentary sequence.

The US is organized in the following units:

iv) Upper Gabbro-Anorthosite Zone (UGAZ), formed by olivine gabbros grading into anorthosites and troctolites with local occurrence of layers and lenses of subophitic coarse grained isotropic gabbros.

v) Upper Amphibolite (UA), formed by amphibole-bearing gabbros interlayered with amphibolites, epidote-bearing gneisses and/or other lithologies of the metavolcanic-metasedimentary sequences. The contact with the stratigraphic upper metavolcanic-metasedimentary sequences (i.e. Palmeirópolis, Indaianopólis and Juscelândia) is magmatic in all the complexes and in both LS and US (Girardi and Kurat, 1982; Girardi et al., 1986; Correia and Girardi, 1998; Ferreira Filho et al., 2010).

The Palmeirópolis, Indaianopólis and Juscelândia sequences show similar stratigraphy and lithologies and are considered fragments of the same crustal sequence (Ferreira Filho et al. 2010 and references therein). The Palmeirópolis Sequence in contact with Cana Brava is the largest (c.a. 80 km long and up to 35 km wide).

These sequences mainly consist of metasedimentary successions (i.e. metacherts, metapelites and calc-silicate rocks) with interbedded amphibolites, gneisses and intrusive and sub-volcanic granites (Brod and Jost 1991; Araújo et al. 1995; Araújo 1996; Moraes and Fuck 1994, 1999; Moraes et al. 2003, 2006; Ferreira Filho et al. 2010). The metavolcanic rocks show geochemical affinities with E-MORB and N-MORB. This compositional variability might indicate a transitional setting from a continental rift to an aborted ocean basin (Araújo, 1996; Moraes et al. 2003, 2006).

Geochronological data on the metavolcanic rocks suggest that the magmatic event occurred during the Mesoproterozoic, between 1.26-1.30 Ga (Pimentel et al., 2000; Moraes et al., 2006; Ferreira Filho et al., 2010). The rocks show metamorphic recrystallization from amphibolite-facies near the contacts with the complexes, where local granulite-facies conditions have also been observed as in the Cafelandia amphibolite (Moraes and Fuck, 1994), to greenschist-facies to the W (Araújo 1996; Moraes et al. 2003, 2006; Ferreira Filho et al. 2010 and references therein).

Previous age data and intrusion models

Although the Barro Alto, Niquelândia and Cana Brava complexes have been the focus of several geochronological studies, a unique interpretation of the intrusion age is still a matter of debate. A review of intrusion age data currently available in the literature is reported in Table 2.

Recent studies have demonstrated that the MZ unit of Niquelândia and Cana Brava during their growth have incorporated rocks from the metavolcanic-metasedimentary sequence (Rivalenti et al., 2008; Correia et al., 2012; Giovanardi et al., 2016). This contamination calls into question the reliability of the whole-rock isochron method applied to date these rocks (contamination evidence are provided for the K-Ar, Ar-Ar, Rb-Sr and Sm-Nd isotopic systematics and for K content; Rivalenti et al., 2008; Correia et al., 2012; Giovanardi et al., 2016). In the frame of this evidence, the only reliable intrusion ages of the complexes are those provided by zircon.

Ferreira Filho et al. (2010) published U-Pb TIMS analyses on zircon grains from gabbros of Cana Brava, obtaining two concordia ages at 782 ± 3 Ma and 779 ± 1 Ma. Giovanardi et al. (2015) published comparable U-Pb SHRIMP-II data, but with slightly older concordia ages, of 792 ± 9 Ma and 778 ± 7 Ma. Both authors have interpreted these ages as intrusion ages.

The presence of inherited zircon cores that provide discordant older ages at 1553, 1493 and 1242 Ma has also been reported (Giovanardi et al., 2015). These ages are consistent with those reported for the formation of the Palmeirópolis Sequence or their inherited sources (Moraes et al., 2003), and thus these cores of zircon grains are interpreted as inherited (Giovanardi et al., 2015).

Similar Mesoproterozoic ages have been reported for zircon grains from the Barro Alto and Niquelândia complexes (Ferreira Filho et al., 1994, 1998; Pimentel et al., 2004, 2006; Correia et al., 1999, 2007, 2012; Della Giustina et al., 2011), together with younger Neoproterozoic ages. The occurrence of two different age clusters (i.e., the Mesoproterozoic and the Neoproterozoic ones) has been interpreted up until now with two different models that are explained in details in the two following sections.

Two-intrusions model

Danni and Leonardos (1981) and Danni et al. (1982) were the first to suggest that Niquelândia consisted of two different complexes with distinct ages, structural and metamorphic recrystallization history. According to them, the older complex represented by the LS was a proto-ophiolitic sequence, while the younger one represented by the US was a metamorphed ocean-floor basalt sequence.

Pimentel et al. (2004) reported U-Pb SHRIMP-RG zircon ages of two samples from the Niquelândia complex. Sample CF03 from the LS gave 24 $^{206}Pb/^{238}U$ ages in the range 855-739 Ma and 14 ages distributed between 1035 Ma and 1959 Ma. Sample CF04 from the US yielded 13 $^{206}Pb/^{238}U$ ages in the range 860-732 Ma and 10 ages distributed between 916 Ma and 1349 Ma. Ferreira Filho et al. (1994) previously dated the same samples by conventional U-Pb method obtaining the same bimodal age distribution. The Neoproterozoic age of the LS sample (CF03) has been interpreted as magmatic, while the older ages, up to 1959 Ma, have been interpreted as due to an inherited component given the correspondent low εNd values typical of crustal contamination (εNd= -5.8; Pimentel et al., 2004). Conversely, Neoproterozoic ages obtained on bright (in cathodoluminescence) zircon rims from sample CF04, representing the US, have been interpreted as metamorphic and the upper intercept of the concordia age at 1248 ± 23 Ma as indicative of the magmatic intrusion of the US. Based on these data, Pimentel et al. (2004, 2006) proposed that Niquelândia was formed by two distinct intrusions, a Mesoproterozoic intrusion and a Neoproterozoic intrusion (the US and the LS, respectively). The same interpretation was successively applied to Cana Brava and Barro Alto complexes (Ferreira Filho et al., 2010; Della Giustina et al., 2011). We note here that this interpretation is opposite to the one of Danni and Leonardos (1981) and Danni et al. (1982), whom consider the LS older than the US, thus reversing the ages of the two intrusions.

Della Giustina et al. (2011) dated three samples from Barro Alto and one sample from the Cafelândia garnet-amphibolite (from the Palmeirópolis sequence) using U-Pb LA-ICPMS on zircon grains. For the US samples, 5 zircon grains from a leucogabbro (sample BAL-09) gave a mean age of 1288 ± 14 Ma, while 5 zircon grains from a garnet-'metanorthosite' (sample BAL-04) yielded ages between 808-735 Ma together with 3 older ages at 904, 1031 and 1117 Ma. The 'mafic granulite' from the LS (sample BAL-05) gave a mean $^{206}Pb/^{238}U$ zircon age at 774 ± 67 Ma, similar to the one obtained from the Cafelândia garnet-amphibolite at 788 ± 46 Ma (Della Giustina et al., 2011). These ages have been interpreted as intrusion ages: the average Mesoproterozoic age for the US intrusion and the Neoproterozoic age for the LS intrusion.

The Mesoproterozoic age of the US intrusion at c.a. 1300 Ma is coeval with the extrusive magmatism recognizable in the upper metavolcano-metasedimentary sequences of Palmeirópolis, Indaianópolis and Juscelândia (Correia et al., 1999; Moraes et al. 2003, 2006; Pimentel et al., 2006; Ferreira Filho et al., 2010), thus relating in time the two events. Crustal contamination in the Neoproterozoic LS is probably related to the intrusion happening in an extensional tectonic event in continental crust (Ferreira Filho et al., 2010; Della Giustina et al., 2011). The mostly coeval age of the LS intrusion (c.a., 770-800 Ma) and magmatic events recorded by the Goiás Magmatic Arc (c.a., 790 Ma) were interpreted by Della Giustina et al. (2011) as the evidence of LS intrusion during an extensional tectonic related to the development of a subduction zone and the origin of a volcanic arc in the Goiás Magmatic Arc.

According to the two-intrusion model, the US of the complexes was metamorphosed during the intrusion of the LS (c.a., 800 Ma) and both were successively recrystallized in granulite- and amphibolite-facies during a regional metamorphic event, which is responsible for the complexes foliation (Ferreira Filho et al., 1994, 2010; Pimentel et al., 2004, 2006; Della Giustina et al., 2011). The age of this metamorphic event is currently unconstrained. The complexes were juxtaposed at 760-750 Ma, possibly during the accretion of the Goiás Magmatic Arc to the São Francisco craton (Della Giustina et al., 2011).

One-intrusion model

Based on field and petrological evidences, Rivalenti et al. (1982) and Girardi et al. (1986) suggested that the LS and the US of Niquelândia represent a single intrusion. They attributed the differences between the LS and the US to polybaric fractionation and were the first to recognize the enrichment of hydrous phases in the MZ, in the US and up to the complex roof and the occurrence of xenoliths from the host Indaianópolis metavolcanic-metasedimentary sequence.

Correia et al. (2007) reported U-Pb SHRIMP zircon ages of two anorthosites: sample Niq1551 from the US of Niquelândia and sample BA-1541 from the US of Barro Alto. The two samples yielded concordia ages of 833 ± 21 Ma and 733 ± 25 Ma, respectively. The authors interpreted them as crystallization ages of the US and, according to literature ages for the LS of Niquelândia and Barro Alto (Pimentel et al., 2004), reproposed the model of the complexes formed during the same igneous event.

Rivalenti et al. (2008) investigated the development of crustal contamination in Niquelândia and modelled the intrusion of the complex suggesting that an anorthositic crystal mush, compatible with the US parent melt, was formed during the segregation of the UZ lithologies.

Correia et al. (2012) provided further U-Pb SHRIMP concordia zircon age on an anorthosite from the Niquelândia US (sample Niq1552) of 780.8 ± 3.7 Ma. This age was interpreted as an intrusion age, although the data distribution suggests that the concordia age could have been affected by younger single-spot ages possibly related to the slow cooling of the complex, and thus they set the intrusion age slightly older at c.a. 790 Ma. In addition, Correia et al. (2012) revised the data of samples CF03 and CF04 and, based on the petrographic evidence provided by Pimentel et al. (2004), concluded that sample CF04 is an embedded xenolith of the metavolcanic-metasedimentary sequence. According to these authors, the Mesoproterozoic ages in Niquelândia US were obtained in inherited zircons (similarly to the interpretation of Mesoproterozoic ages in sample CF03 of Pimentel et al., 2004). They also were the first to report field evidence of late undeformed layers and domains with magmatic texture, which crosscut the over-imposed foliation interpreted as metamorphic in the literature. Correia et al. (2012) concluded that the LS and US of Niquelândia are parts of the same body that intruded via multiple-melt pulses under syn-magmatic hyper- to sub-solidus shear conditions. According to this model, the high-T recrystallization observed in several parts of the complex has occurred during the slow-cooling process and is not due to later metamorphic events. The metasomatic process that affected the three complexes, giving rise to serpentinites, talc-carbonate rocks, rodingites (in Cana Brava, Dreher et al. 1989), is a much later event associated to local fracturing at low temperature (about 400°; Girardi et al. 1991; Biondi, 2014).

Recent studies on Cana Brava have provided preliminary U-Pb SHRIMP zircon ages coeval to Niquelândia (4 samples concordia age at 788 ± 2.1 Ma; Giovanardi et al., 2015) and similar field structures suggesting that the complex has grown under hyper- to sub-solidus deformation (Giovanardi et al., 2016).

Samples and analytical methods

Zircons were separated after crushing, milling, magnetic and heavy liquid separation and hand picking from 4 samples of Cana Brava and 2 samples from Barro Alto.

Zircons were separated from Cana Brava rocks to definitely constrain their age of intrusion: among the three complexes Cana Brava is the least known and only few and preliminary data are reported in literature. Samples from Cana Brava (named CB1030, CB1100, CB1175 and CB1382) are gabbros and a diorite from different stratigraphic levels in the MZ and were selected among the samples collected from limited available *in place* outcrop (the soil alteration and the vegetation of the area often cover the outcrops and only blocks are recognizable).

Sample CB1175 is a granoblastic gabbro from the middle of the stratigraphic succession of the MZ, while samples CB1100 and CB1382 and sample CB1030, respectively, are representative of granoblastic gabbros and subordinated diorites outcropping near the roof of Cana Brava (Fig. 2). Gabbro CB1175 was collected at 13°28'0.01"S and 48°16'3.61"O; it shows a foliation parallel to the complex direction (i.e. NNE) due to the alignment of pyroxenes and plagioclase. Biotite is commonly associated to amphibole, which is the most abundant hydrous phase. Minor amounts of K-feldspar and quartz are also recognized. Spinel and zircon occur as accessory phases.

Sample CB1100, a non-foliated almost-anhydrous gabbro from the roof of the complex, was collected at 13°29'10.48"S and 48°18'38.12"O; amphibole is the only hydrous phase and it occurs in minor amount. Orthopyroxene is largely subordinated to clinopyroxene. Spinel is more abundant with respect to other samples. Sample CB1382, a hydrous foliated gabbro from the complex roof, was collected at 13°22'6.06"S and 48°15'32.05"O; Foliation results from alignment of pyroxenes, plagioclase and biotite. Biotite is the most abundant hydrous phase but amphibole also occurs. Spinel, quartz and K-Feldspar occur in minor amounts. Zircon and apatite occur as accessory phases. Sample CB1030, a diorite pod near the complex roof, was collected at 13°22'9.49"S and 48°15'21.99"O. Orthopyroxene is more abundant than clinopyroxene. Biotite is the major hydrous phase, while amphibole is accessory. K-feldspar and quartz are more abundant than in gabbros. Apatite, titanite and zircons occur as accessory phases.

Notwithstanding that Barro Alto is more studied than Cana Brava, its intrusion age is still debated. Therefore, we decided to separate zircons from one gabbro from the MZ (BA06T) and from one anorthosite from the UGAZ (BA01T) in order to constrain the ages of LS and US and clarify the correct model of formation of the complex.

Sample BA06T is a granoblastic coarse-grained gabbro outcropping in the upper part of the MZ near the roof of the complex and the contact with the Palmeirópolis Sequence in the W-E part of Barro Alto (15°12'51.04"S and 49°11'23.94"O; Fig. 4). A magmatic stratification, parallel to the complex direction, is recognizable from an alternance of layers of femic minerals (pyroxenes and amphibole) and plagioclase. Amphibole occurs in minor amount often associated to clinopyroxene. Spinels are abundant as interstitial phase in femic layers. Zircon occurs as accessory phase.

Sample BA01T is a granoblastic coarse-grained anorthosite from the UGAZ outcropping in the N-S part of Barro Alto (15°05'02.13"S and 48°59'17.91"O; Fig. 4). Clinopyroxene and amphibole occur as interstitial phases along deformed bands. In these bands, minor amounts of spinel and orthopyroxene are also recognized. Apatite and rutile occur as accessory phases.

After Au-coating, the polished zircon mounts were comprehensively examined with a FEI-QUANTA 250 scanning electron microscope equipped with secondary-electron and cathodoluminescence (CL) detectors at IGc-CPGeo-USP. The most common conditions used in CL analysis were 60 μA of emission current, 15.0 kV of accelerating voltage, 7 μm of beam diameter, 200 μs of acquisition time, and a resolution of 2048x1887 pixels and 345 dpi. The same mounts were afterwards analyzed for U-Pb isotopes by SHRIMP-IIe machine also at IGc-CPGeo, Universidade de São Paulo, following the analytical procedures presented in Williams (1998). Correction for common Pb was based on the measured ^{204}Pb, and the typical error component for the $^{206}Pb/^{238}U$ ratio is less than 2%; U abundance and U-Pb ratios were calibrated against the TEMORA standard and age calculations were performed with Isoplot© 4.1 (Ludwig, 2009). Data are reported in Table 3.

Results

Cana Brava gabbros from the MZ of the Lower Sequence

Zircon grains from sample CB1175 are colourless and have anhedral to sub-euhedral habits. CL images show complex structures composed by irregular chaotic oscillatory zoning and domains often superimposed by other structures (Fig. 6). When occurring, linear zoning is partially erased. Zircon grains from samples near the complex roof are colourless and commonly have sub-euhedral habits (Figs. 7, 8 and 9). Anhedral crystals are rare. CL images show similar structures among the three samples. Zircon grains often present black cores with partially deleted zoning or domains and a brighter magmatic oscillatory zoning or domains growth (Figs. 7, 8 and 9). Rarely, the cores are bright and show evidence of resorption with formation of a partially deleted complex structure. Often the core structures are truncated by one or more growth accretion of new domains or oscillatory zoning. In sample CB1100, the rim structures are brighter and sometimes reabsorb the previous growth structure with superimposed accretion (Fig. 8).

In all samples, zircon grains composed only by oscillatory zoning are recognizable (Figs. 7, 8 and 9).

Twenty-one U-Pb SHRIMP-II analyses were obtained from 15 zircon grains of sample CB1175, 28 analyses from 17 zircon grains of sample CB1030, 7 analyses from 7 zircon grains of sample CB1100 and 5 analyses from 4 zircon grains of sample CB1382.

Analyses from sample CB1175 show $^{206}Pb/^{238}U$ single spot ages ranging from 819 ± 14 Ma to 791 ± 14 Ma, defining a weighted average of 802 ± 7 Ma (2σ, MSWD = 0.20, probability of concordance = 1.00). However, the data give an extremely poor concordia age of 796 ±4 Ma (2σ, decay-const. errs included, MSWD = 6.8, probability of concordance = 0.009).

$^{206}Pb/^{238}U$ single spot ages from sample CB1030 range from 801 ± 23 Ma to 756 ± 22 Ma, defining a weighted average of 778 ± 3 Ma (2σ, MSWD = 0.49, probability of concordance = 0.99) and a concordia age of 779 ± 3 Ma (2σ, decay-const. errs included, MSWD = 4.0, probability of concordance = 0.047). One core analysis yielded an older age of 1150 ± 8 Ma.

Analyses from sample CB1100 gave $^{206}Pb/^{238}U$ single spot ages ranging from 795 ± 23 Ma to 762 ± 22 Ma, defining a weighted average of 781 ± 7 Ma (2σ, MSWD = 0.26, probability of concordance = 0.96) and a concordia age of 783 ± 7 Ma (2σ, decay-const. errs included, MSWD = 1.2, probability of concordance = 0.27). Two older discordant analyses on zircon cores yielded ages of 866 ± 7 Ma and 829 ± 7 Ma.

$^{206}Pb/^{238}U$ single spot ages from sample CB1382 range from 786 ± 6 Ma to 774 ± 8 Ma, defining a weighted average of 780 ± 6 Ma (2σ, MSWD = 0.44, probability of concordance = 0.78) and a concordia age of 781 ± 6 Ma (2σ, decay-const. errs included, MSWD = 2.2, probability of concordance = 0.13).

Barro Alto gabbro from the MZ of the Lower Sequence

Zircon grains from BA06T are colourless with euhedral to sub-euhedral habits. No inclusions were recognized.

In CL, zircon grains show two different zoning: a darker internal linear zoning and, in the zircon rims, a brighter zoning commonly organized in domains (Fig. 10). The brighter external domain zoning commonly envelops the internal zoning but follows the same growth direction.

Twenty-one analyses were carried out on 15 zircon grains.

$^{206}Pb/^{238}U$ single spot ages range from 761 ± 20 Ma and 812 ± 14 Ma, with a weighted average of 789 ± 6 Ma (2σ, MSWD = 0.73, probability of concordance = 0.76). Four analyses show older ages: three are from dark cores and are discordant; one is a concordant age from the rim of one of the crystals (analyses 6.1, 9.1, 9.2 and 12.1; Fig. 10). The two older discordant ages from the dark cores gave $^{206}Pb/^{238}U$ single spot ages of 1438 ± 43 Ma and 1083 ± 20 Ma. The rim yielded a concordant $^{206}Pb/^{238}U$ single spot age of 892 ± 14 Ma. Last, the core of zircon 12 gave a discordant $^{206}Pb/^{238}U$ single spot age of 836 ± 14 Ma.

Excluding these four older analyses, zircon grains from sample BA06T define a concordia age of 790 ± 6 Ma (2σ, decay-const. errs included, MSWD = 1.2, probability of concordance = 0.27).

Barro Alto anorthosite from the UGAZ of the Upper Sequence

Zircon grains from BA01T are colourless with rounded anhedral to subeuhedral habits. Small rounded inclusions have been identified in two crystals. CL images show different and complex structures (Fig. 11). Usually, zoning is partially to completely erased, and appears as a dark/grey homogeneous area. In the few zoned grains, the crystals have small cores with different internal structure and overgrowth zoning (Fig. 11). Extremely bright domains overgrow discordantly all the other structures (Fig. 11).

Nineteen analyses were performed on 16 zircon grains. Eleven analyses gave concordant ages ranging between 842 ± 16 Ma and 770 ± 11 Ma ($^{206}Pb/^{238}U$ single spot age, 1σ error), a weighted average of 802 ± 14 Ma (95% confidence error level, MSWD = 3.4) and a concordia age of 801 ± 9

Ma (95% confidence error level, decay-const. errs included, MSWD = 0.016, probability of concordance = 0.90).

Three older discordant $^{206}Pb/^{238}U$ single spot ages of 2052 ± 25 Ma, 1318 ± 16 Ma and 889 ± 17 Ma were obtained in two zircons. Five younger discordant ages in three zircons released $^{206}Pb/^{238}U$ single spot ages ranging between 644 ± 8 Ma and 600 ± 8 Ma.

Discussion

Age of the complexes

Our new ages of Cana Brava, ranging from 819 ± 14 Ma to 756 ± 22 Ma, are slightly older than previously reported ages of 782-779 Ma (Ferreira Filho et al., 2010) and of 792-778 Ma (Giovanardi et al., 2015). However, all together these data suggest that the intrusion of Cana Brava took place in a time span of at least c.a. 30 Ma (800-770 Ma).

Cana Brava ages reflect the stratigraphic position of the samples: gabbro CB1175 from the middle part of the MZ, yielded older ages than samples CB1100, CB1382 and CB1030 from near the roof of the complex ($^{206}Pb/^{238}U$ average ages at 802 ± 7 Ma and 781-778 Ma respectively). Among samples from the complex roof, diorite CB1030 is slightly younger than gabbros CB1100 and CB1382 ($^{206}Pb/^{238}U$ average ages at 778 ± 3 Ma and 780 ± 6 - 781 ± 7 Ma, respectively). Based on petrographic evidences, diorites in the Goiás complexes are interpreted in literature as formed by fractionation of a late melt (Correia et al., 2012; Giovanardi et al., 2016). The new U-Pb data support this hypothesis. The samples stratigraphic positions, the magmatic crystallization evidences and the U/Pb ages suggest that the Cana Brava intrusion occurred in a relatively long time span that permitted the partial closure of the zircon system before the end of the intrusion. Taken together new and literature ages from Cana Brava are equally distributed between 800-770 Ma and show comparatively younger ages between 770-750 Ma with a few data down to 700 Ma (Fig. 12). This constant sharp decrease could be associated to the slow cooling of the complex. The absence of younger, significantly separated age spikes from the intrusive event is consistent with the hypothesis that Cana Brava has not been recrystallized by regional metamorphic events after its crystallization. This idea, previously suggested by Giovanardi et al. (2016) on structural evidence, is now supported by the equal distribution of ages between 800 and 770 Ma and the evidence that the age distribution is directly related to the stratigraphic position of the samples and their crystallization age. The few ages between 800 and 820 Ma are interpreted as related to the initial stage of the one-intrusion event, while older ages, always found in zircon cores, are interpreted to be inherited zircons from xenoliths of the metavolcanic-metasedimentary sequence.

U/Pb zircon ages from the Barro Alto gabbro from the MZ of the LS (sample BA06T) show a restricted time span similar to the Cana Brava samples (between 800-770 Ma), suggesting a coeval intrusion age for the two complexes. Zircon grains from the Barro Alto anorthosite from the UGAZ of the US mainly gave slightly older concordant ages, but coeval within errors, with the Barro Alto gabbro ($^{206}Pb/^{238}U$ average ages at 802 ± 14 Ma and 789 ± 6 Ma, respectively). This evidence supports the scenario that anorthosites and gabbros are part of the same intrusion, as previously suggested for Niquelândia (Correia et al., 2007, 2012; Rivalenti et al., 2008). The fact that anorthosite ages are slightly older than gabbro ages is also in agreement with the idea that the anorthosite crystallized from a plagioclase-rich crystal mush separated during the initial segregation of the ultramafic cumulates (i.e., the UZ) (Rivalenti et al., 2008; Correia et al., 2012). We interpret few older ages in the MZ gabbro and in the UGAZ anorthosite as inherited zircon grains from the metavolcanic-metasedimentary sequence. The discordant nature of these ages is possibly ascribed to a rejuvenation effect of partial re-opening of the zircon system and/or Pb loss during residence in the magmatic chamber. This rejuvenation mechanism could have also affected four crystals in the anorthosite with discordant ages between 644-600 Ma. These ages are currently the youngest ever reported in the literature for the three complexes (e.g. Pimentel et al., 2004, 2006; Correia et al., 2007, 2012; Ferreira Filho et al., 2010; Della Giustina et al., 2011; Giovanardi et al., 2015). However, their discordant nature and the absence of similar zircon data suggest that they could be the result of Pb loss during local tectonism (visible in the many faults and shear zones in the area), possibly related to the bending/exhumation of the complex. A similar age at 650 Ma was obtained from U-Pb dating of rutile from Niquelândia and interpreted as consistent with the tectonic event responsible for the exhumation of the complex (Ferreira Filho et al., 1994, 1998).

Our new data from Barro Alto suggest that the mafic-ultramafic LS and the US units are coeval and genetically related to the same intrusion event between 800-770 Ma, similarly to what observed in Niquelândia (Correia et al., 2007, 2012; Rivalenti et al., 2008). Our data also support the interpretation of a common exhumation scenario of the complexes between 600 and 650 Ma.

Inconsistencies in Barro Alto US ages

Although our data of Barro Alto definitely confirm a Neoproterozoic intrusion age for the US and LS units, literature ages of the US around 1.30-1.27 Ga and of supposed 'metamorphic ages' around 800 Ma reveal a more complicated history (Table 2; Fig. 13), whereas the LS data are more consistent with the 800-770 Ma interval for the intrusion (Fig. 13).

So far, four samples from the Barro Alto US have been studied: three anorthosites and one leucogabbro. The Neoproterozoic ages from our Barro Alto US anorthosite BA01T ($^{206}Pb/^{238}U$ ages between 842 ± 16 Ma and 770 ± 11 Ma) are consistent with previously obtained ages from another anorthosite (sample BAL-04 of Della Giustina et al. 2011), with similar few older discordant ages. Ages reported from US anorthosite BA-1541 define discordant younger ages ranging from 799 ± 36 Ma down to 726 ± 26 Ma (Correia et al., 2007), however, compatible with the two previous ages. Thus, these three anorthosites from the US indicate a coeval Neoproterozoic intrusion age with the LS gabbros (800-770 Ma; this study). Conversely, a US leucogabbro (sample BAL-09 of Della Giustina et al., 2011) defines Mesoproterozoic ages from 1301 ± 15 Ma down to 1127 ± 17 Ma, thus, suggesting that the intrusion age of the Barro Alto US occurred between 1.29 and 1.27 Ga (ages obtained from the average concordant ages of sample BAL-09 and from the upper intercept of sample BAL-04 considering the older discordant ages). Della Giustina et al. (2011) have also reported Lu-Hf isotopic ratios of zircons and have recalculated εHf(t) to the ages estimated by their two-intrusion model: at 1.29 Ga for BAL-09 zircons (US), at 1.27 Ga for BAL-04 zircons (US) and at c.a. 800 GA for BAL-05 zircons (LS). The recalculated εHf(t) are indicative of mantle values for the US zircons and of crustal values for the LS (εHf(t) = 5.13 to 7.22 for BAL-09, 7.00 to 9.88 for BAL-04 and -7.84 to -12.76 for BAL-05). These results are consistent with Rb-Sr and Sm-Nd isotope systematics and indicate crustal contamination of the MZ of the LS in Niquelândia and Cana Brava, and none or poor contamination of the US (Rivalenti et al., 2008; Correia et al., 2012; Giovanardi et al., 2016). It is worth noticing that, the Neoproterozoic zircon grains from sample BAL-04 (Della Giustina et al., 2011) result in positive eHf(t) when recalculated to the age inferred by their model, however, they become mainly negative εHf(t) from 0.06 to -4.68, when recalculated to their measured U-Pb age (Fig. 14). The single Mesoproterozoic zircon grain from the same sample shows a positive εHf(t) at 6.04 consistent with values from the BAL-09 US leucogabbro (Fig. 14). Assuming the zircon ages as crystallization ages, Mesoproterozoic and Neoproterozoic zircon grains define two different εHf(t) groups, the first one with mantle values and the second one with more crustal values (Fig. 14). Similar εHf(t) positive mantle values have been found in zircon grains from the Cafelandia amphibolite (Della Giustina et al., 2011), commonly interpreted as part of the metavolcanic-metasedimentary sequence (Moraes and Fuck, 1994; Moraes et al., 2003, 2006). This evidence suggests that, similarly to what observed in the LS and other complexes, the Mesoproterozoic zircon grains within the Barro Alto US are inherited from the metavolcanic-metasedimentary sequence. This scenario is also supported by the anomalous morphology and CL structure of the BAL-09 zircon grains compared to other zircon grains showed in this work and in literature for gabbroic rocks of the three complexes. In particular, they are described as fragments with 'stubby habit with rounded terminations, which render oval morphologies' and with CL images revealing ‘texture indicating metamorphic recrystallization' (Della Giustina et al., 2011). These features are described in zircon grains from gabbroic rocks only in Mesoproterozoic cores from inherited zircons, which are commonly overgrowth by magmatic oscillatory CL zoning zircons with euhedral to sub-euhedral habits (see Figs. 9 and 10 and CL images in Pimentel et al., 2004; Correia et al., 2007, 2012; Giovanardi et al., 2015).

The εHf(t) from 0.06 to -4.68 of sample BAL-04 are consistent with Rb-Sr and Sm-Nd bulk rock data and suggest that anorthosites fractionated early during the complexes intrusion from poorly/un-contaminated melts during the segregation of the UZ (Rivalenti et al., 2008; Correia et al., 2012). Because zircon grains crystallize as a late phase during mafic intrusions, they can record, more accurately than other minerals, the contamination of the anorthositic residual melts. According to the different degrees of crustal contamination in the US and LS, Neoproterozoic zircons from the US anorthosite BAL-04 show εHf(t) values that are less contaminated than those from the LS sample BAL-05.

In summary, according to U-Pb zircon data reported in this study, literature ages from Barro Alto anorthosites (US samples BAL-04 and BA-1541) and the review of literature Mesoproterozoic inherited zircon grains, we conclude that the Barro Alto LS and US are coeval and crystallized during the same igneous event during the Neoproterozoic.

Which model?

The new U-Pb zircon ages of Cana Brava and Barro Alto constrain the intrusion of the two complexes as coeval and between 770 and 800 Ma. Furthermore, the new Barro Alto data, together with literature data, indicate that the crystallization of LS and US in this complex occurred during the same igneous event. These evidences are in agreement with the one-intrusion event model and rule out the possibility that the Barro Alto and Niquelândia complexes were formed by two distinct igneous events as previously proposed.

The U-Pb zircon age distribution in both Cana Brava and Barro Alto complexes and the absence of ages younger than the intrusive event further support the hypothesis that the complexes deformation occurred during their growth in hyper- to sub-solidus shear conditions and that regional metamorphism does not overprint the Goiás complexes. Similar geochemical and structural evidences have been also discussed for Niquelândia (Correia et al., 2012).

The fact that US anorthosites commonly show slightly older ages than MZ gabbros in both Barro Alto and Niquelândia complexes (Correia et al., 2012; this study) also suggests that these lithologies were formed from an anorthositic crystal mush probably separated during the segregation of the UZ at the beginning of the complexes crystallization. The least contaminated εHf(t) values for the Neoproterozoic zircon grains of the Barro Alto anorthosite with respect to the zircon grains of the gabbros are consistent with this scenario.

Based on structural evidences such as the occurrence of late undeformed magmatic layers crosscutting the super-imposed foliation and layers repetition in the stratigraphy, it has been proposed that the large mafic-ultramafic Goiás complexes has grown via multiple melt pulses (Correia et al., 2012; Giovanardi et al., 2016). This hypothesis seems confirmed by the U-Pb ages of Cana Brava, which show a direct correlation between the age and the stratigraphic position of the sample.

The Tonian Goiás Stratiform Complex and its geodynamic significance

Because of their petrographic, chemical and isotopic similarities, the three Goiás complexes, together with the associated metavolcanic metasedimentary sequences, were long considered related to each other (Danni et al., 1982; Ferreira Filho, 1998; Ferreira Filho et al., 1994, 2010; Correia et al., 2007, 2012; Della Giustina et al., 2011; Giovanardi et al., 2016). Ferreira Filho (1998) was the first to suggest that the three complexes are fragments of a larger body, based on the almost identical stratigraphy of the three complexes (see chapter 'geological setting'), the geochemical and petrological similarities of their lithologies and the identical ‘metamorphic overprint’. However, this hypothesis was discarded after the re-introduction of the two-intrusions model (Pimentel et al., 2004).

The idea of a single body was later reproposed based on geophysical and gravimetric data (Carminatti et al., 2006).

However, the first U-Pb zircon ages obtained from Cana Brava (Tab. 2; Ferreira Filho et al., 2010) defined a slightly younger age (770 Ma) than the then available Barro Alto and Niquelândia literature ages (780-800 Ma; Pimentel et al., 2004, 2006; Correia et al., 2007). Thus, it was concluded that the three complexes were not only formed by two distinct events, but were also separated intrusions (Ferreira Filho et al., 2010).

However, the new U-Pb zircon data of Cana Brava postdated the intrusion of the complex as coeval to the others (770-790 Ma). It has also been recognized that Cana Brava shows evidence of syn-magmatic deformation similarly to Niquelândia (Correia et al., 2012; Giovanardi et al., 2016). Moreover, geochemical variations, xenolith occurrence and lithology and estimated thicknesses along the stratigraphic succession of Cana Brava are comparable to those of the LS of Niquelândia (Giovanardi et al, 2016). According to these evidences and to the bending of the layering in the south tectonic contact of Cana Brava (Fig. 2), Giovanardi et al. (2016) suggested, that the two complexes are part of the same body, which was fragmented in boudins possibly during the accretion at the São Francisco craton or earlier after the end of the complexes intrusion.

Although some parts of the original body between Niquelândia and Cana Brava are missing, due to the later tectonic events that accreted, rotated and exhumed the complexes, the structure of the single large body comprising Cana Brava and Niquelândia is similar (but specular) to Barro Alto. Giovanardi et al. (2016) proposed that the body feeding centres were mainly located in correspondence of Niquelândia, where the stratigraphy is more evolved and complete.

The new U-Pb data of Barro Alto and the constraints on the one-intrusion event model provided by this study all suggest that Barro Alto is coeval and geochemically similar to the Niquelândia-Cana Brava pluton and possibly represent the southern fragment of a unique giant intrusion.

This scenario is also supported by similar stratigraphies, identical syn-magmatic deformation, specular shapes of Barro Alto and Niquelândia-Cana Brava pluton, and crustal contamination recognized in zircons from Barro Alto similar to the contamination within Niquelândia and Cana Brava. We thus propose to name this single large body as the Tonian Goiás Stratiform Complex (TGSC hereafter; according to the new International Chronostratigraphic Chart, v2016/04; Cohen et al., 2013; Shield-Zhou et al., 2016).

In this framework, the estimated structure of the TGSC is symmetrical, thicker in the centre (corresponding to the Niquelândia complex and the N-S oriented portion of Barro Alto) and thinned and almost disappearing at the margins (the E-W oriented portion of Barro Alto and the Cana Brava complex). The TGSC body had a length of at least c.a. 200 km with a maximum estimated thickness of c.a. 20 km. These are important dimensions, comparable to other large layered complexes recognized worldwide, such as the Bushveld (66000 km^2), Dufek (50000 km^2), Duluth (4700 km^2), Stillwater (4400 km^2), Muskox (3500 km^2) complexes (and others).

According to structural evidence in the Niquelândia and Cana Brava complexes, the TGSC has grown by multiple melt pulses that during the crystallization formed a crystal mush deformed by the stress field conditions derived from an active tectonic setting (Correia et al., 2012; Giovanardi et al., 2016; this study). Given the stratigraphy of the Cana Brava MZ and the slightly older ages of the US compared to the LS, the age distribution supports the multiple pulses model and suggests that the time-span of the pulses was relatively slow compared to the crystallization and deformation processes. This timespan has allowed not only the crystallization of zircons, but also the closure of the U-Pb zircon system. Another evidence for this model is the full tectonic accommodation of the complex within continental crust, which differs from other layered complexes because it formed in active tectonic setting (e.g., the Val Sesia-Val Sessera mafic complex, Italy; Quick et al., 1992, 1994; Sinigoi et al., 2010 and references therein) and, therefore, shows an extremely linear structure parallel to the deformation. The segregation model of the US of Niquelândia (Rivalenti et al., 2008), the increase in crustal contamination along the MZ of Niquelândia and Cana Brava and the increase of crustal delamination, as revealed by the highest abundance of xenoliths at the top of the MZ (Rivalenti et al., 2008; Correia et al., 2012; Giovanardi et al., 2016), all suggest that the heating of the metavolcanic-metasedimentary sequence and the thermal and delamination effects of the TGSC occurred progressively, until the late stages of intrusion.

Given that the US units occur only in Niquelândia and in the N-S segment of Barro Alto, we possibly identify the central and thickest part of the TGSC structure in this area. According to the model of segregation of the US units during the early magmatic stages (Rivalenti et al., 2008), we infer that the TGSC intrusion started in this central area, as the main feeding centre, and later expanded laterally. This lateral expansion and the segregation of the E-W Barro Alto segment and Cana Brava would have possibly helped to sustain the large TGSC body during its growth.

Several geodynamic scenarios for the intrusion of the three Goiás complexes have been proposed: oceanic ridge (Danni and Leonardos, 1981; Danni et al., 1982), continental rifting (Ferreira Filho et al., 1998; Pimentel et al., 2004, 2006; Ferreira Filho et al., 2010; Della Giustina et al., 2011) or back-arc extension in continental crust near a subduction setting (Della Giustina et al., 2011).Among these hypotheses, the oceanic ridge scenario was discarded because it was quickly recognized that the Goiás complexes are not ophiolites (Rivalenti et al., 1982; Girardi et al., 1986) and that the metavolcanic metasedimentary sequence is representative of old continental crust (Araujo, 1996; Moraes et al., 2003, 2006).

The evidence of syn-magmatic deformation during the TGSC growth, the large volume of magma accomodated during the intrusion and the evidence of crustal delamination suggest an active tectonic setting for the TGSC intrusion. However, as discussed by Kröner and Cordani (2003) and Cordani et al. (2003), no evidences for a Neoproterozoic rifting are visible in the outcrops of the Brasilia Belt. Instead, as suggested by Della Giustina et al. (2011), the intrusion of the TGSC is coeval with the extensive magmatism of the Goiás Magmatic Arc at c.a. 790 Ma and, in particular, within the Mara Rosa Arc outcropping in the central and northern parts of the Brasilia Belt to the E-NE of the TGSC (Fig 1). Thus, we conclude that a back-arc extensional setting in continental crust, probably related to the subduction that originated the Goiás Magmatic Arc, is currently the best geodynamic scenario for the intrusion of the TGSC.

Concluding remarks

New U-Pb zircon data on rocks from the Cana Brava and Barro Alto complexes provide evidence for a coeval intrusion of the two igneous bodies during the Neoproterozoic, between 770-800 Ma and for a coeval history with Niquelândia.

The new ages and a review of literature data constrain the intrusion of the lower and upper sequences of Barro Alto to the same igneous event, ending a long debate over the one- or two-intrusions models for the emplacement of the complexes.

The new ages, together with a review of the stratigraphy and geochemical evidence of the three complexes, suggest that the three Goiás layered complexes are fragments of a single large body, here called the Tonian Goiás Stratiform Complex, intruded at the bottom of a continental crust that consisted of a metavolcanic metasedimentary sequence in a back-arc setting during a subduction event that led to the formation of the Goiás Magmatic Arc at c.a. 790 Ma.

The slightly older ages obtained from anorthosites of the upper sequences of both Barro Alto and Niquelândia support the idea that these rocks formed by a plagioclase-rich crystal mush that was separated during the segregation of the ultramafic unit at the early stages of intrusion.

The age distribution of the Tonian Goiás Stratiform Complex supports a growth model via multiple pulses, forming a crystal mush under shear condition. The absence of significant age spikes younger than the complex intrusion, together with structural and field work evidence suggest that the high-T recrystallization that partially affected the Tonian Goiás Stratiform Complex occurred during the long cooling process and is not the consequence of metamorphic events. Few U-Pb zircon discordant ages between 600-640 Ma are comparable with a U-Pb rutile age at 650 Ma and are thus interpreted as exhumation ages of the Tonian Goiás Stratiform Complex.

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Figure Captions

Fig. 1: regional geotectonic setting of the Brasilia Belt modified after Pimentel et al. (2006). Each complex is identified with the number of the figure of the detailed geological map reported in this article.

Fig. 2: geological map of the Cana Brava complex, modified after Correia et al. (1997) and Ferreira Filho et al. (2010).

Fig. 3: geological map of the Niquelândia complex, modified after Correia et al. (2012).

Fig. 4: geological map of the Barro Alto complex, modified after Ferreira Filho et al. (2010).

Fig. 5: field evidence from the Barro Alto complex; a) outcrop of altered ultramafic rocks (15°15'41.87"S, 49°08'27.53"O) within the basal gabbros; b) pyroxenite layers within basal gabbro; c) xenolith within the gabbro from upper MZ in the E-W segment of the complex; d) xenolith (amphibolite) within the anorthosite of UGAZ in the N-S segment of the complex.

Fig. 6: CL images of zircon grains from MZ Cana Brava gabbro sample CB1175 with reported number of the single spot analysis; calculated concordia and average $^{206}Pb/^{238}U$ age (errors are calculated as 2σ).

Fig. 7: CL images of zircon grains from MZ Cana Brava gabbro sample CB1030 with reported number of the single spot analysis; calculated concordia and average $^{206}Pb/^{238}U$ age (errors are calculated as 2σ).

Fig. 8: CL images of zircon grains from MZ Cana Brava diorite sample CB1100 with reported number of the single spot analysis; calculated concordia and average $^{206}Pb/^{238}U$ age (errors are calculated as 2σ).

Fig. 9: CL images of zircon grains from MZ Cana Brava gabbro sample CB1382 with reported number of the single spot analysis; calculated concordia and average $^{206}Pb/^{238}U$ age (errors are calculated as 2σ).

Fig. 10: CL images of zircon grains from MZ Barro Alto gabbro sample BA06T with reported number of the single spot analysis; calculated concordia age (errors are calculated as 2σ) and probability density plot of $^{206}Pb/^{238}U$ ages.

Fig. 11: CL images of zircon grains from UGAZ Barro Alto anorthosite sample BA01T with reported number of the single spot analysis; calculated concordia age (errors are calculated as 2σ) and probability density plot of $^{206}Pb/^{238}U$ ages.

Fig. 12: probability density plot of $^{206}Pb/^{238}U$ ages obtained for the Cana Brava complex: data are from samples CB1175, CB1030, CB1100 and CB1382 from this study and Giovanardi et al. (2015).

Fig. 13: probability density plot of $^{206}Pb/^{238}U$ ages obtained for the Barro Alto complex in this study and literature: a) ages from the US rocks: sample BA01T (anorthosite) is from this study, (a) sample BAL-09 (leucogabbro) and sample BAL-04 (anorthosite) from Della Giustina et al. (2011), (b) sample BA-1541 (anorthosite) from Correia et al. (2007); b) ages from LS rocks: sample BA06T (gabbro) from this study, (a) sample BAL-05 (gabbro) from Della Giustina et al. (2011).

Fig. 14: recalculated εHf(t) for zircon grains with measured U-Pb ages from Della Giustina et al. (2011). The depleted mantle (DM) evolution line is calculated using the values of present-day $^{176}Hf/^{177}Hf$ ratio of 0.28325 from Nowell et al. (1998) and $^{176}Lu/^{177}Hf$ ratio of 0.0384 from Griffin et al. (2000). CHUR values are from Blichert-Toft and Albarede (1997).

Fig. 15: tectonic sketch of the Tonian Goiás Stratiform Complex intrusion and growth according to the proposed geodynamic model. The N-S dash line in the tectonic model represent the view section of the below growth model sketch.

Table captions

Table 1: comparison of the literature stratigraphies of the Goiás complexes and the new proposed lithologic subdivision.

Table 2: summary of literature U-Pb zircon ages (Ma) of the Goiás complexes and of the metavolcanic-metasedimentary sequences.

Table 3: SHRIMP-II analyses on zircons from the Cana Brava complex and calculated ages.

Table 4: SHRIMP-II analyses on zircons from the Barro Alto complex and calculated ages.

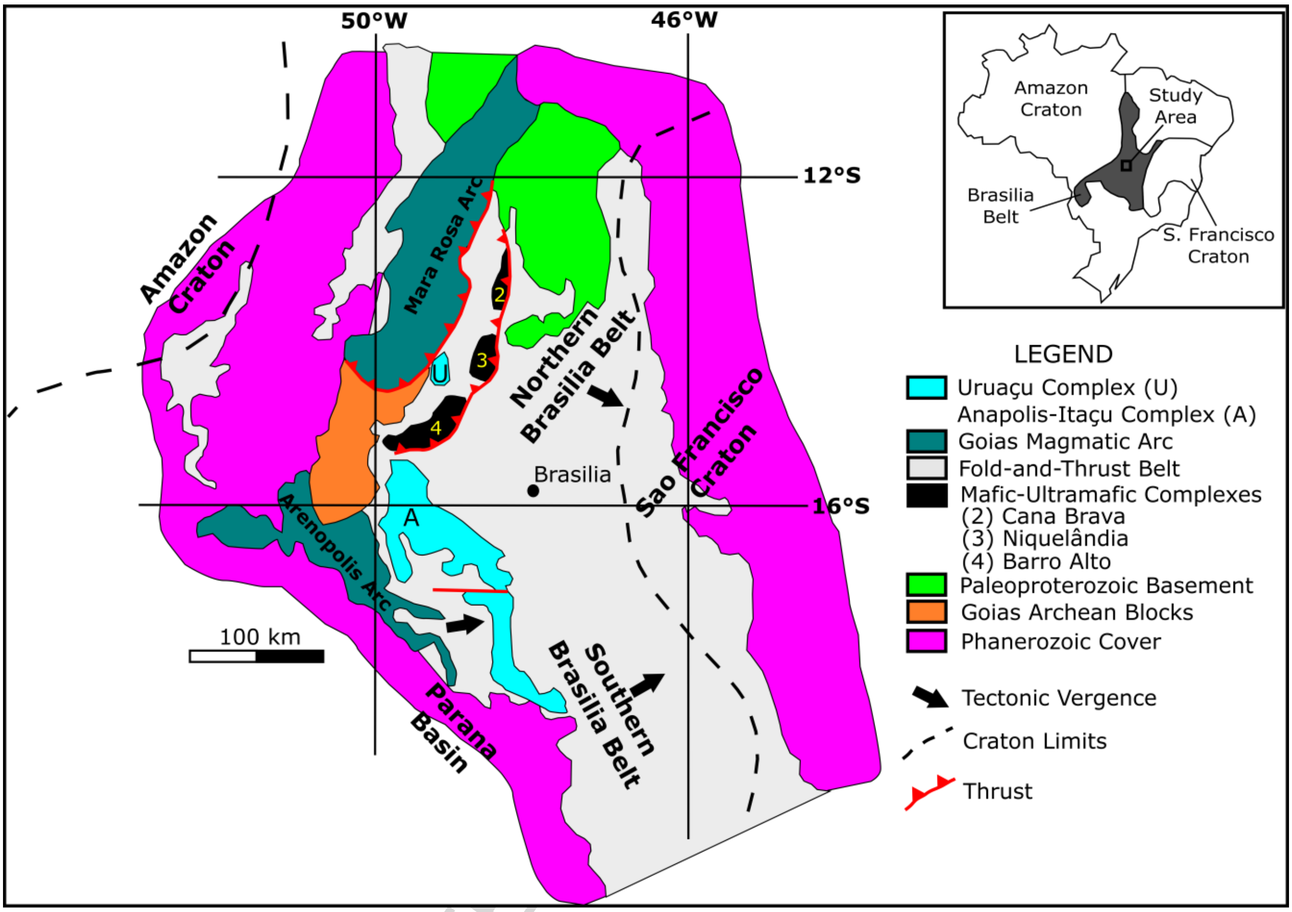

50°W
46°W
12°S
16°S
Amazon Craton
Mara Rosa Arc
Northern Brasilia Belt
Sao Francisco Craton
Brasilia
Arenopolis Arc
Parana Basin
Southern Brasilia Belt
100 km
U
A
2
3
4
Amazon Craton
Study Area
Brasilia Belt
S. Francisco Craton
LEGEND
Uruaçu Complex (U)
Anapolis-Itaçu Complex (A)
Goias Magmatic Arc
Fold-and-Thrust Belt
Mafic-Ultramafic Complexes
(2) Cana Brava
(3) Niquelândia
(4) Barro Alto
Paleoproterozoic Basement
Goias Archean Blocks
Phanerozoic Cover
Tectonic Vergence
Craton Limits
Thrust

Figure 1

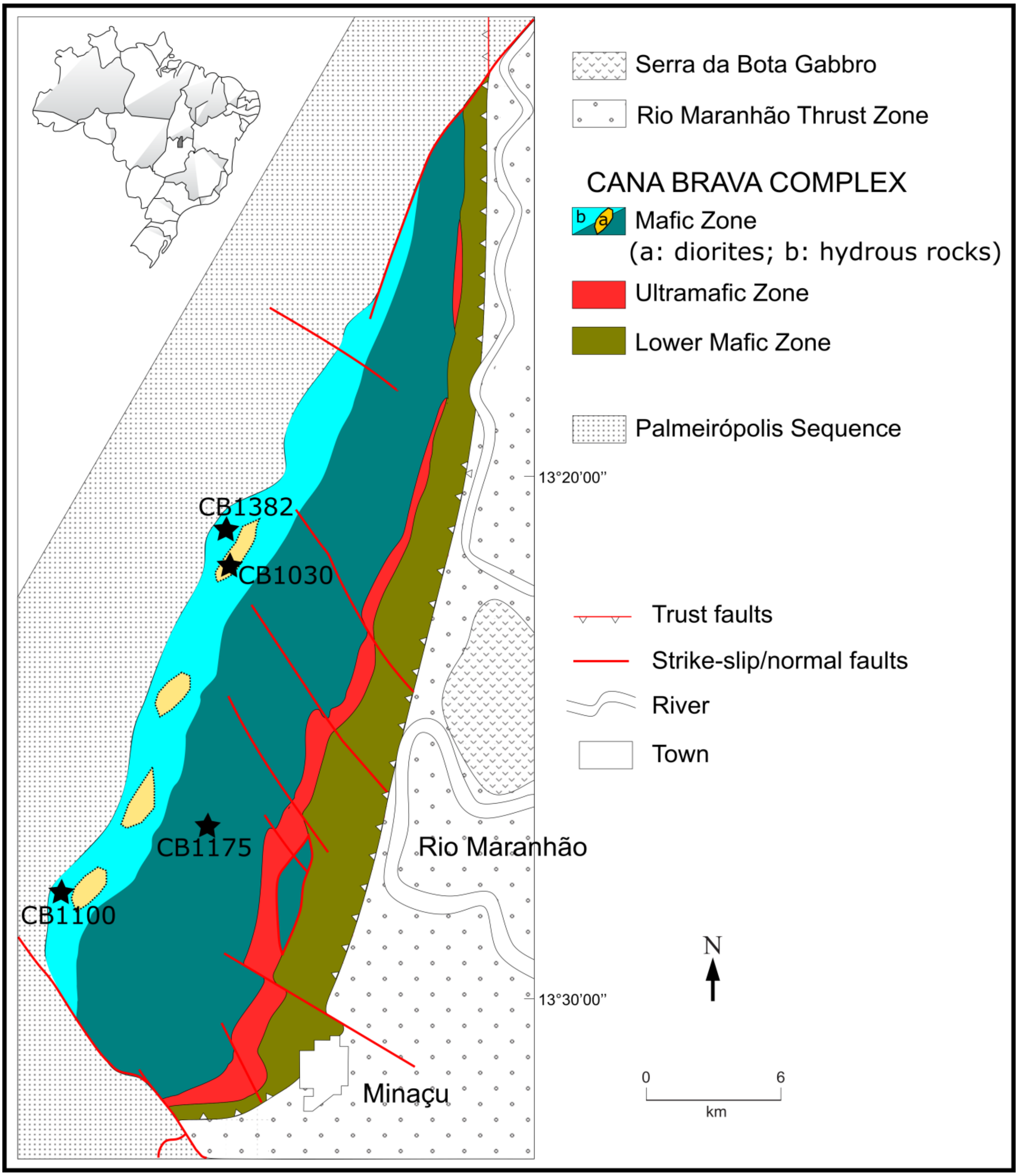

Serra da Bota Gabbro
Rio Maranhão Thrust Zone
CANA BRAVA COMPLEX
b
a
Mafic Zone
(a: diorites; b: hydrous rocks)
Ultramafic Zone
Lower Mafic Zone
Palmeirópolis Sequence
13°20'00''
CB1382
CB1030
CB1175
CB1100
Trust faults
Strike-slip/normal faults
River
Town
Rio Maranhão
N
13°30'00''
Minaçu
0
6
km

Figure 2

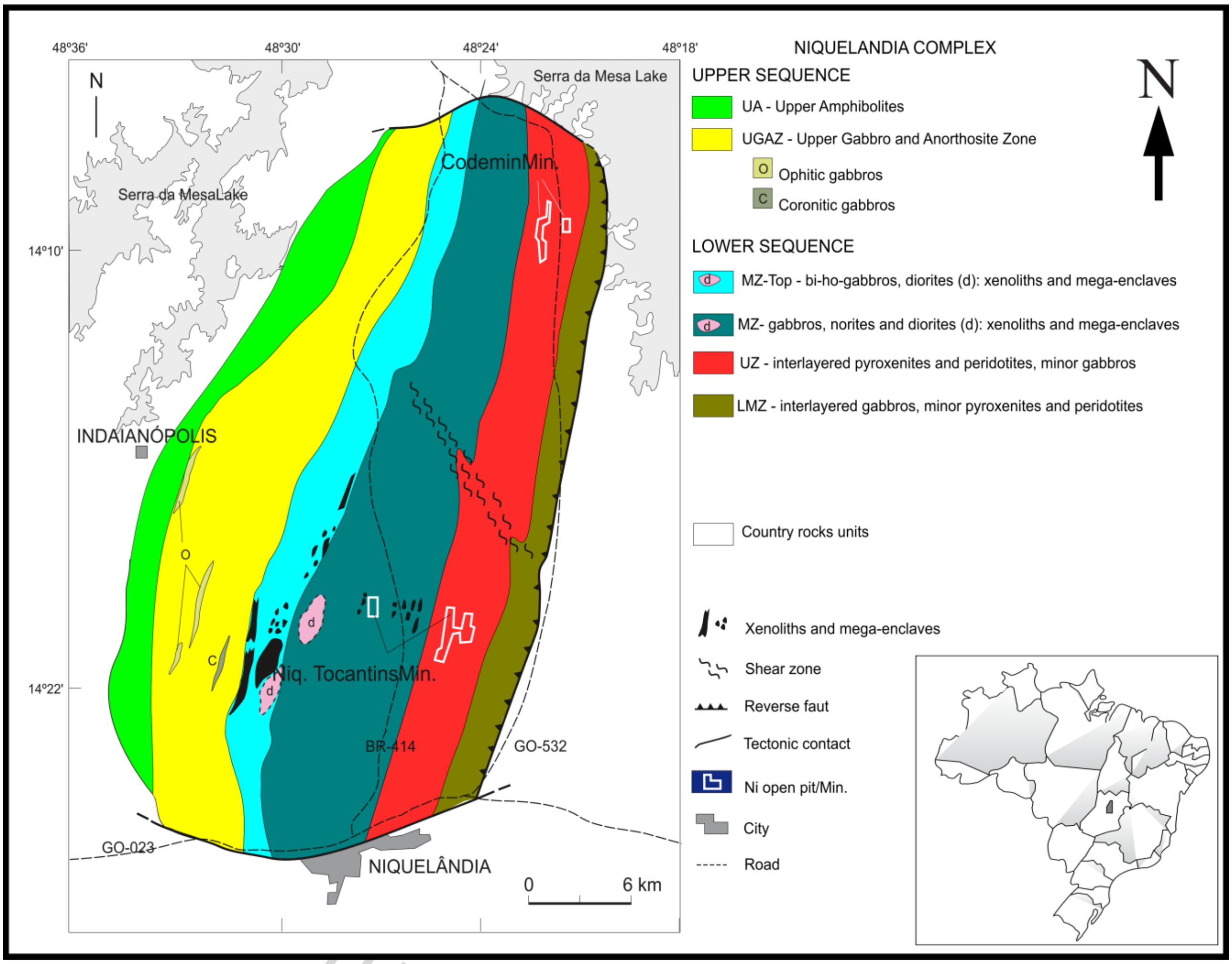

48°36'
48°30'
48°24'
48°18'
14°10'
14°22'
N
Serra da Mesa Lake
Serra da MesaLake
CodeminMin.
INDAIANÓPOLIS
O
C
d
Niq. TocantinsMin.
BR-414
GO-532
GO-023
NIQUELÂNDIA
0
6 km
NIQUELANDIA COMPLEX
UPPER SEQUENCE
UA - Upper Amphibolites
UGAZ - Upper Gabbro and Anorthosite Zone
Ophitic gabbros
Coronitic gabbros
LOWER SEQUENCE
MZ-Top - bi-ho-gabbros, diorites (d): xenoliths and mega-enclaves
MZ- gabbros, norites and diorites (d): xenoliths and mega-enclaves
UZ - interlayered pyroxenites and peridotites, minor gabbros
LMZ - interlayered gabbros, minor pyroxenites and peridotites
Country rocks units
Xenoliths and mega-enclaves
Shear zone
Reverse faut
Tectonic contact
Ni open pit/Min.
City
Road

Figure 3

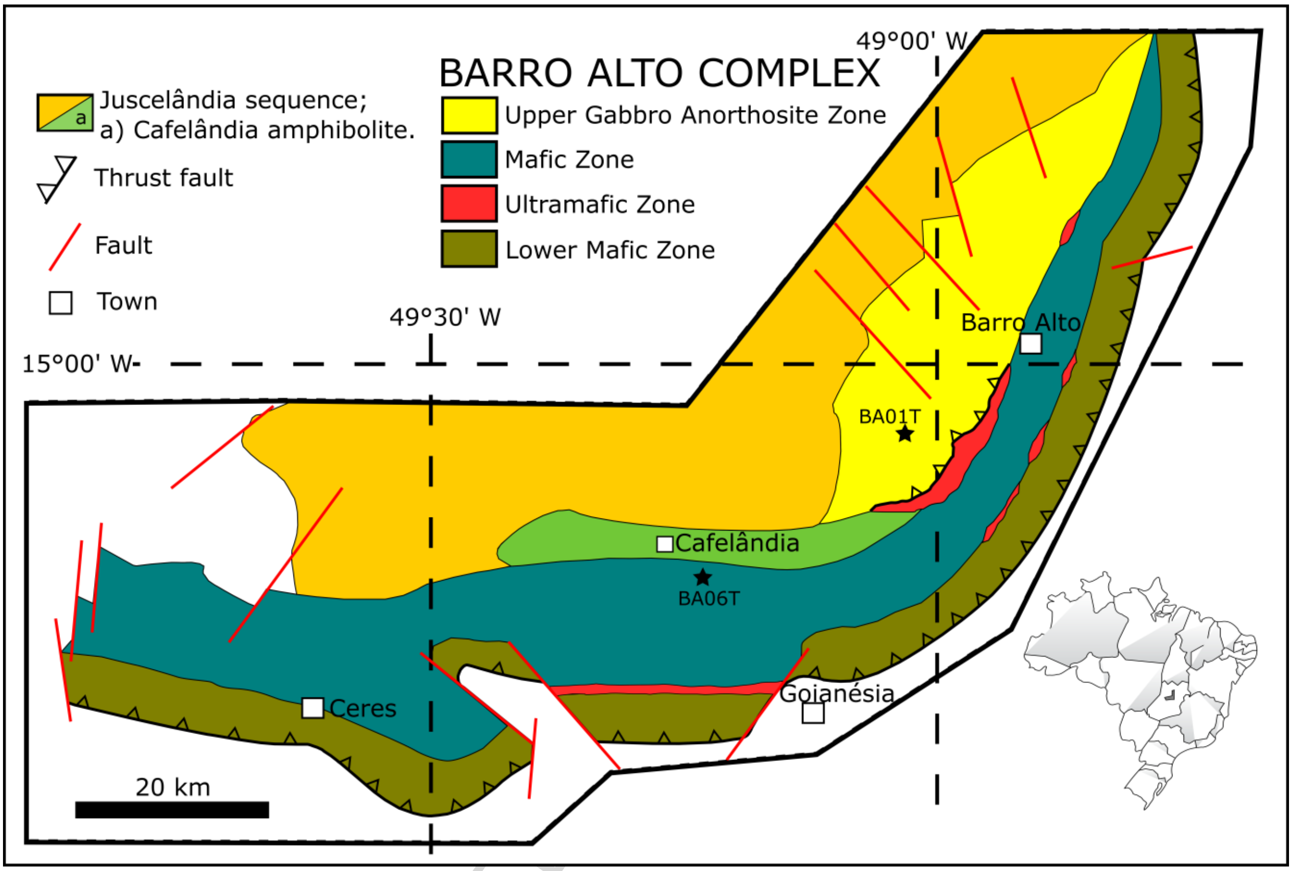

BARRO ALTO COMPLEX
Juscelândia sequence;
a) Cafelândia amphibolite.
a
Thrust fault
Fault
Town
Upper Gabbro Anorthosite Zone
Mafic Zone
Ultramafic Zone
Lower Mafic Zone
49°00' W
49°30' W
15°00' W
Barro Alto
BA01T
Cafelândia
BA06T
Goianésia
Ceres
20 km

Figure 4

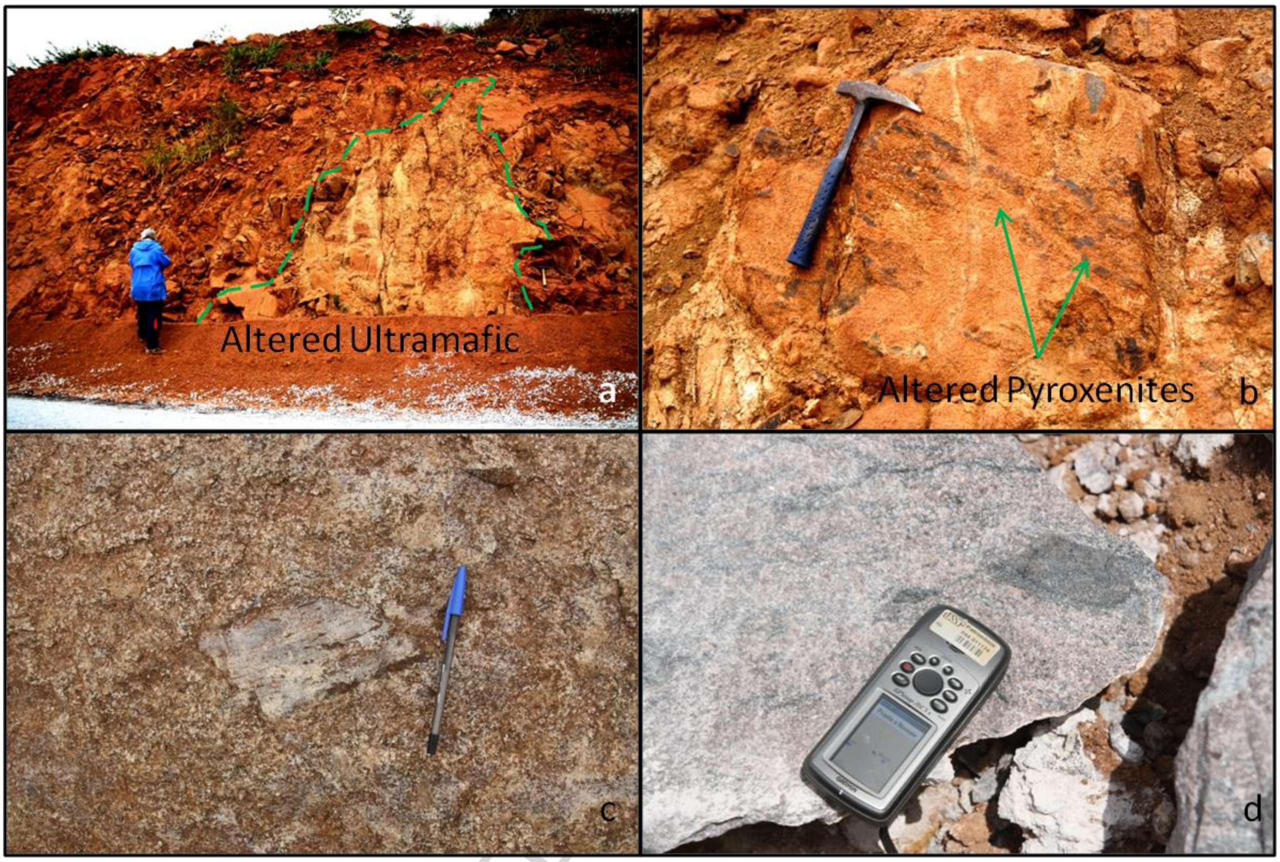
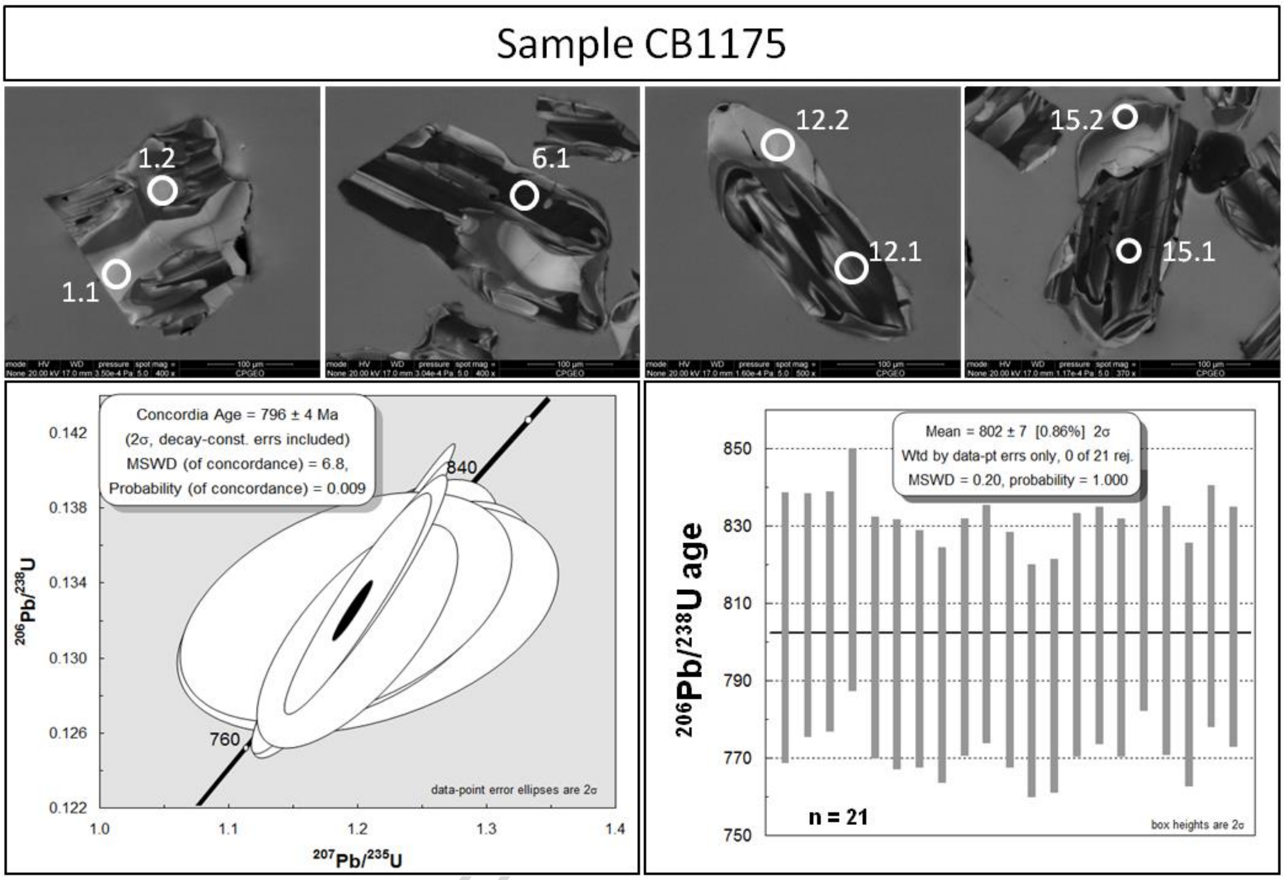
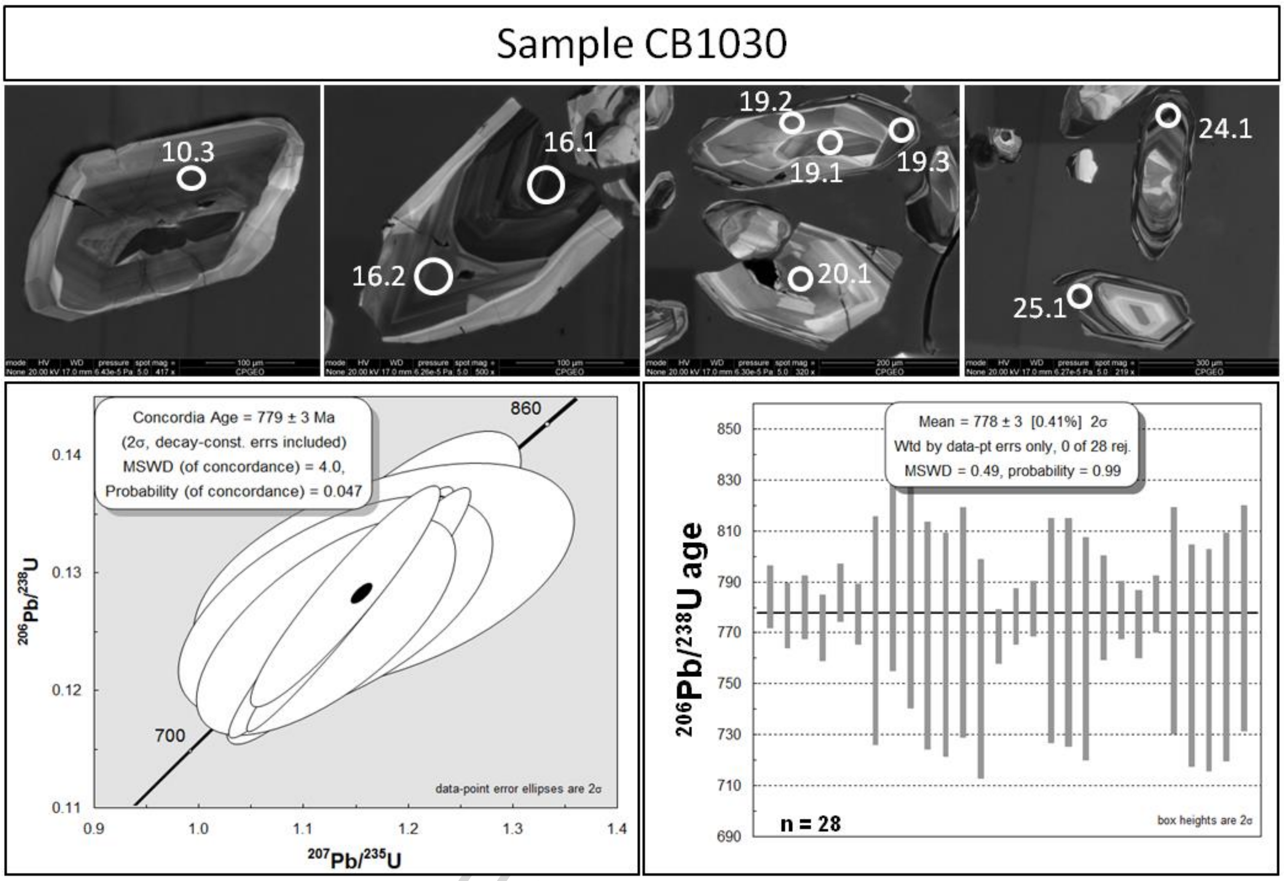


Figure 5



Sample CB1175
1.2
1.1
6.1
12.2
12.1
15.2
15.1
Concordia Age = 796 ± 4 Ma
(2σ, decay-const. errs included)
MSWD (of concordance) = 6.8,
Probability (of concordance) = 0.009
840
760
data-point error ellipses are 2σ
$^{206}Pb/^{238}U$
$^{207}Pb/^{235}U$
Mean = 802 ± 7 [0.86%] 2σ
Wtd by data-pt errs only, 0 of 21 rej.
MSWD = 0.20, probability = 1.000
$^{206}Pb/^{238}U$ age
n = 21
box heights are 2σ

Figure 6



Sample CB1030
10.3
16.1
16.2
19.2
19.1
19.3
20.1
24.1
25.1
Concordia Age = 779 ± 3 Ma
(2σ, decay-const. errs included)
MSWD (of concordance) = 4.0,
Probability (of concordance) = 0.047
860
700
data-point error ellipses are 2σ
206Pb/238U
207Pb/235U
Mean = 778 ± 3 [0.41%] 2σ
Wtd by data-pt errs only, 0 of 28 rej.
MSWD = 0.49, probability = 0.99
206Pb/238U age
n = 28
box heights are 2σ

Figure 7

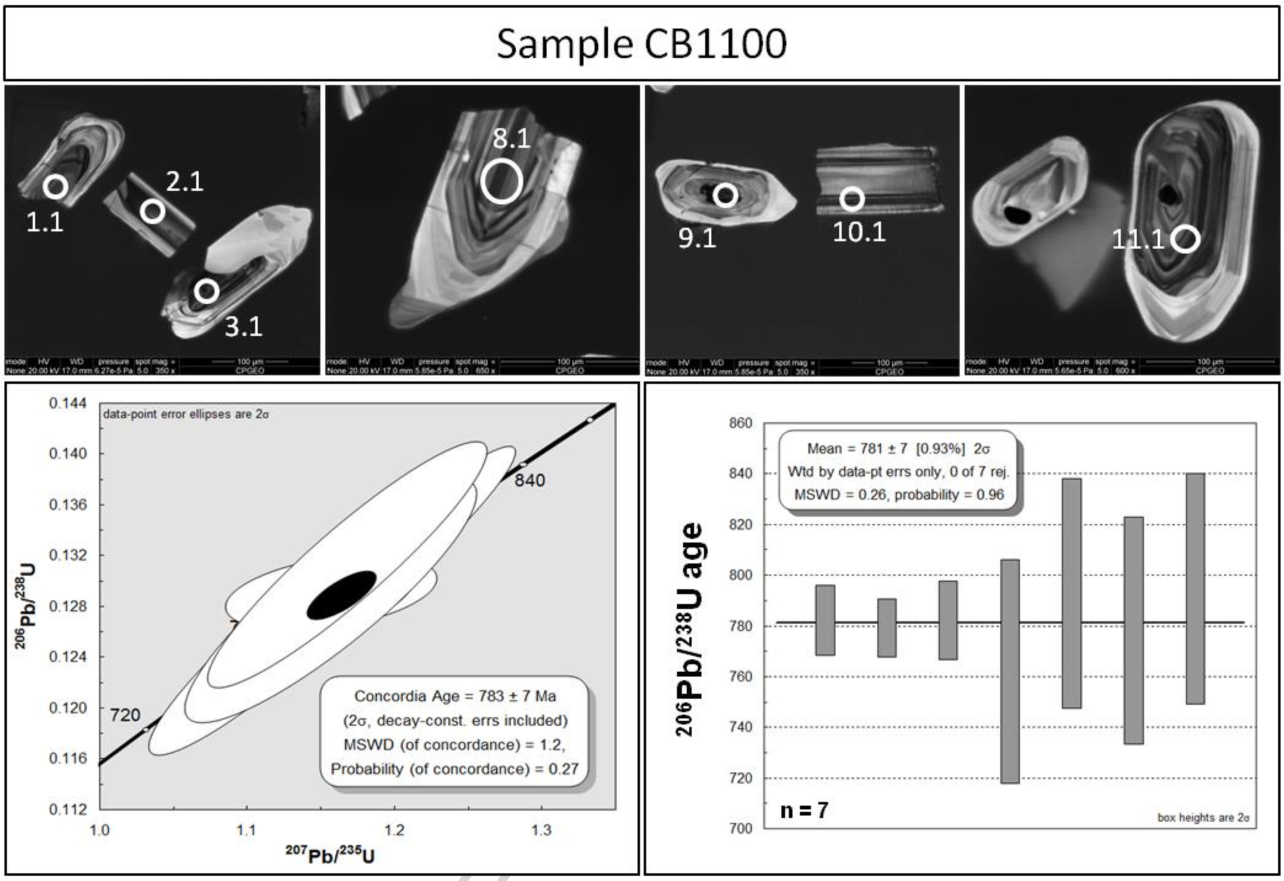

Sample CB1100
1.1
2.1
3.1
8.1
9.1
10.1
11.1
data-point error ellipses are 2σ
840
720
Concordia Age = 783 ± 7 Ma
(2σ, decay-const. errs included)
MSWD (of concordance) = 1.2,
Probability (of concordance) = 0.27
206Pb/238U
207Pb/235U
Mean = 781 ± 7 [0.93%] 2σ
Wtd by data-pt errs only, 0 of 7 rej.
MSWD = 0.26, probability = 0.96
206Pb/238U age
n = 7
box heights are 2σ

Figure 8

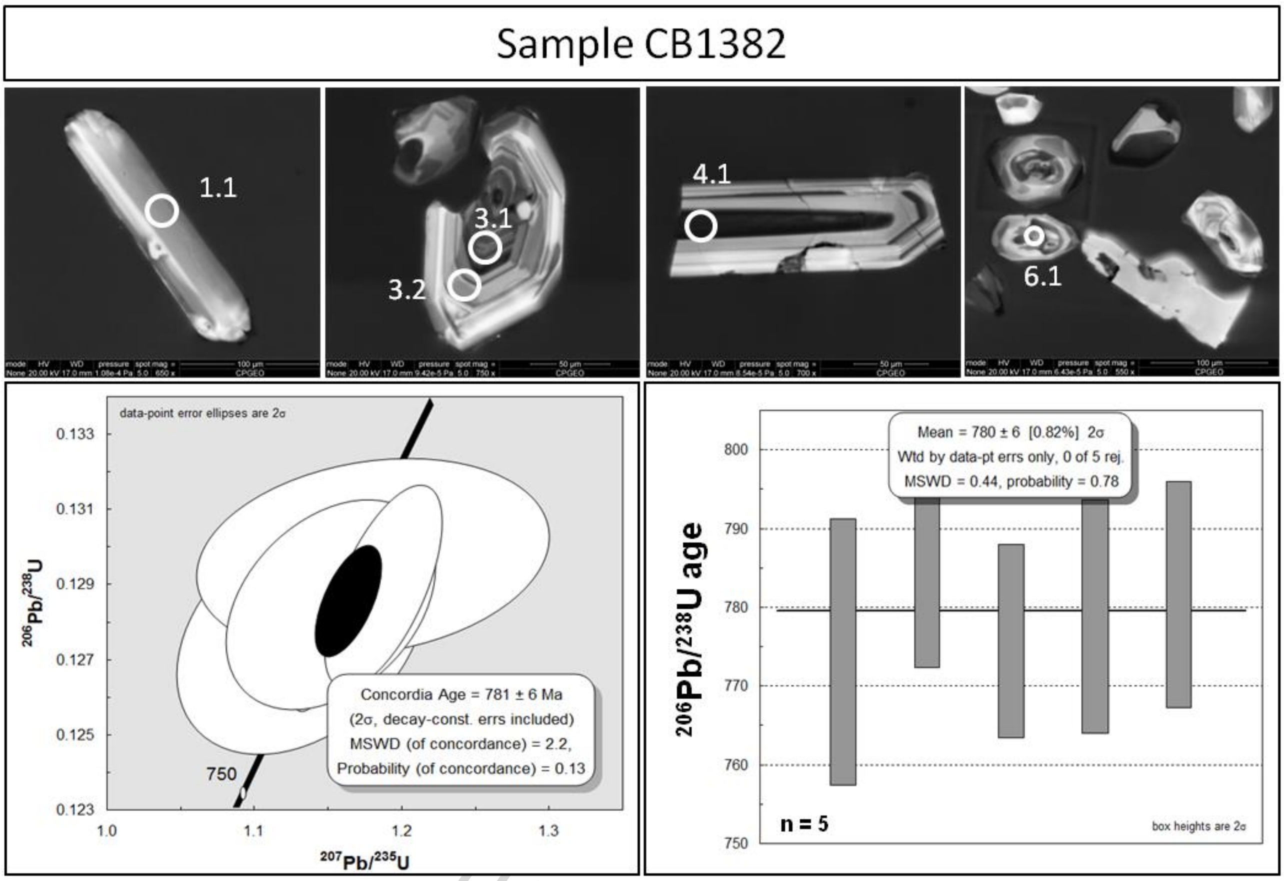

Sample CB1382
1.1
3.1
3.2
4.1
6.1
data-point error ellipses are 2σ
0.133
0.131
0.129
0.127
0.125
0.123
206Pb/238U
750
Concordia Age = 781 ± 6 Ma
(2σ, decay-const. errs included)
MSWD (of concordance) = 2.2,
Probability (of concordance) = 0.13
1.0
1.1
1.2
1.3
207Pb/235U
Mean = 780 ± 6 [0.82%] 2σ
Wtd by data-pt errs only, 0 of 5 rej.
MSWD = 0.44, probability = 0.78
800
790
780
770
760
750
206Pb/238U age
n = 5
box heights are 2σ

Figure 9

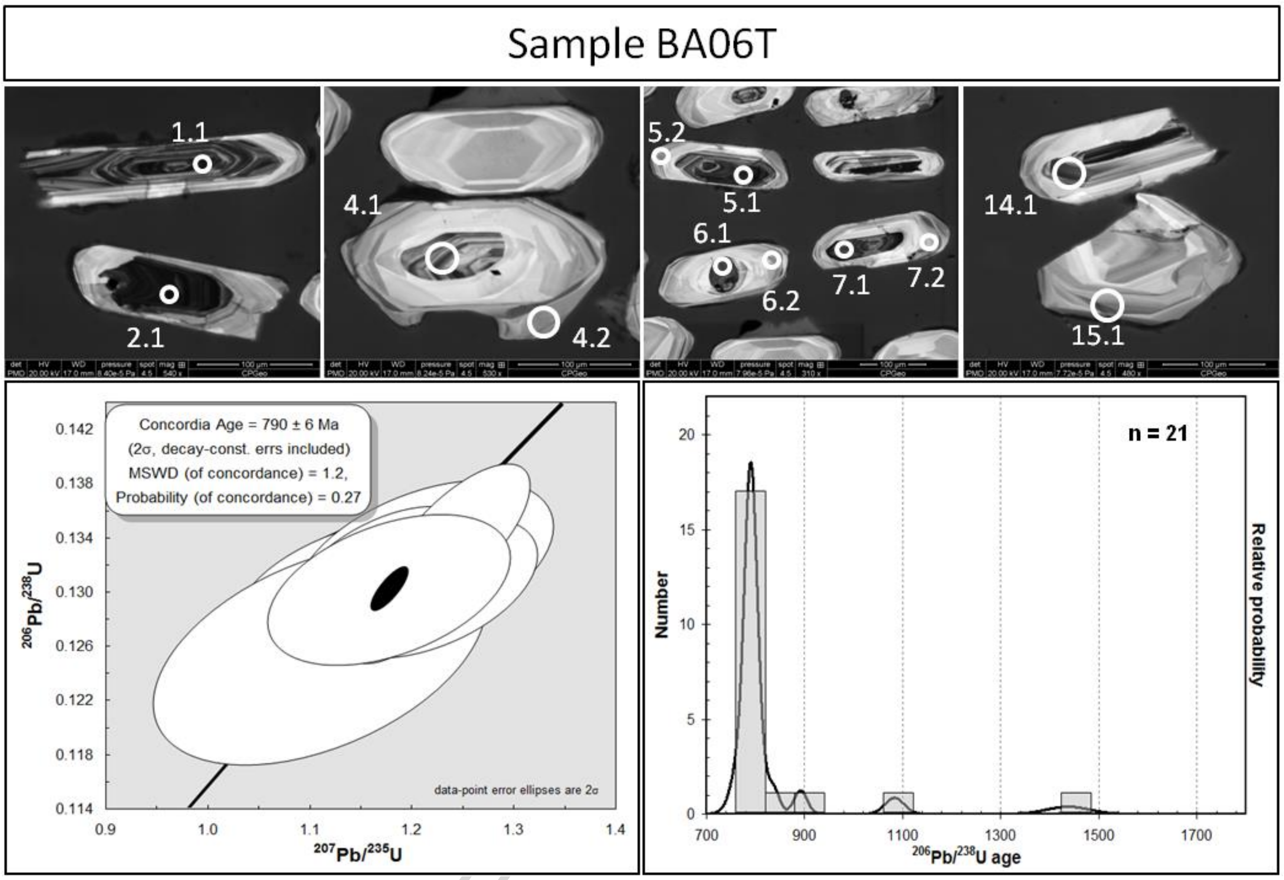

Sample BA06T
1.1
2.1
4.1
4.2
5.2
5.1
6.1
6.2
7.1
7.2
14.1
15.1
Concordia Age = 790 ± 6 Ma
(2σ, decay-const. errs included)
MSWD (of concordance) = 1.2,
Probability (of concordance) = 0.27
data-point error ellipses are 2σ
206Pb/238U
207Pb/235U
n = 21
Number
Relative probability
206Pb/238U age

Figure 10

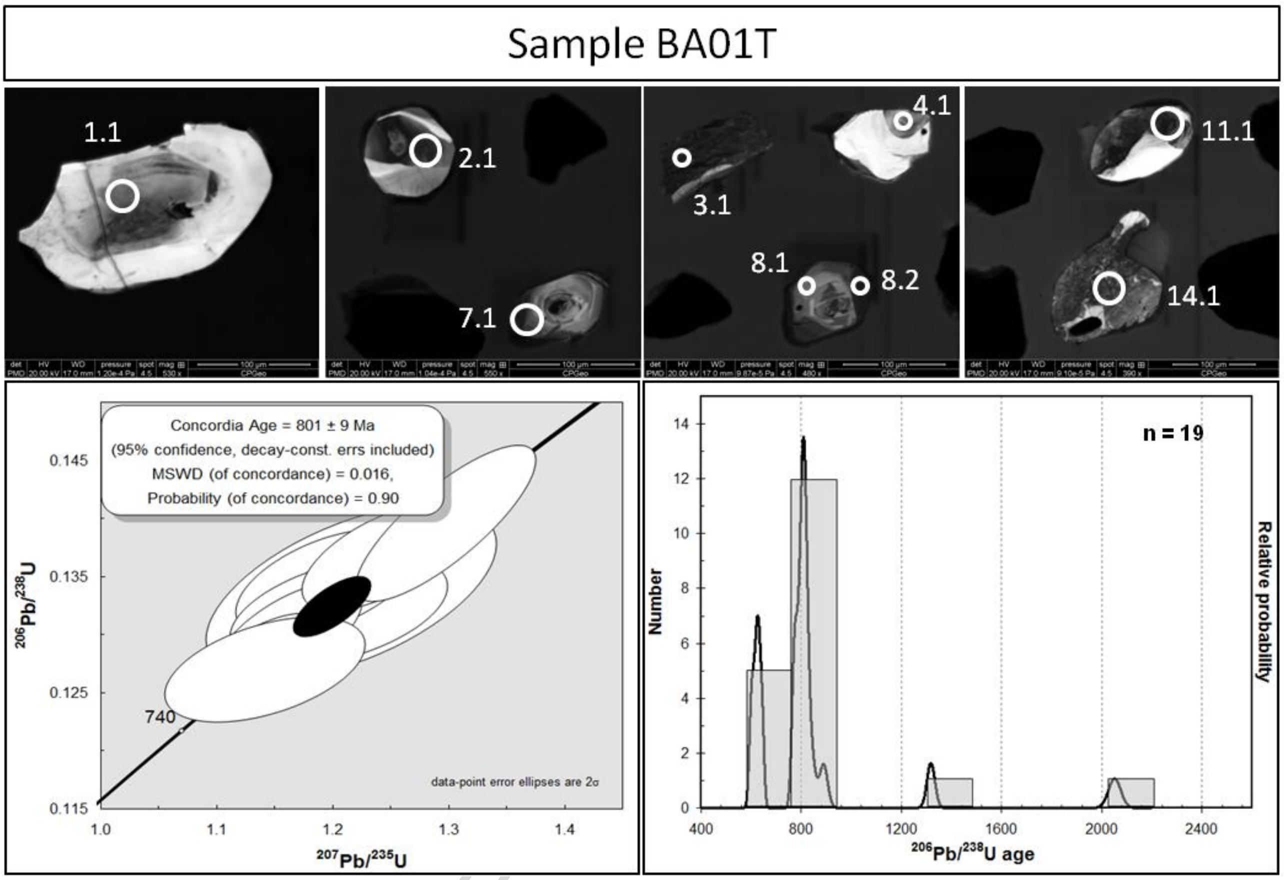

Sample BA01T
1.1
2.1
7.1
4.1
3.1
8.1
8.2
11.1
14.1
Concordia Age = 801 ± 9 Ma
(95% confidence, decay-const. errs included)
MSWD (of concordance) = 0.016,
Probability (of concordance) = 0.90
740
data-point error ellipses are 2σ
$^{206}Pb/^{238}U$
$^{207}Pb/^{235}U$
n = 19
Number
Relative probability
$^{206}Pb/^{238}U$ age

Figure 11

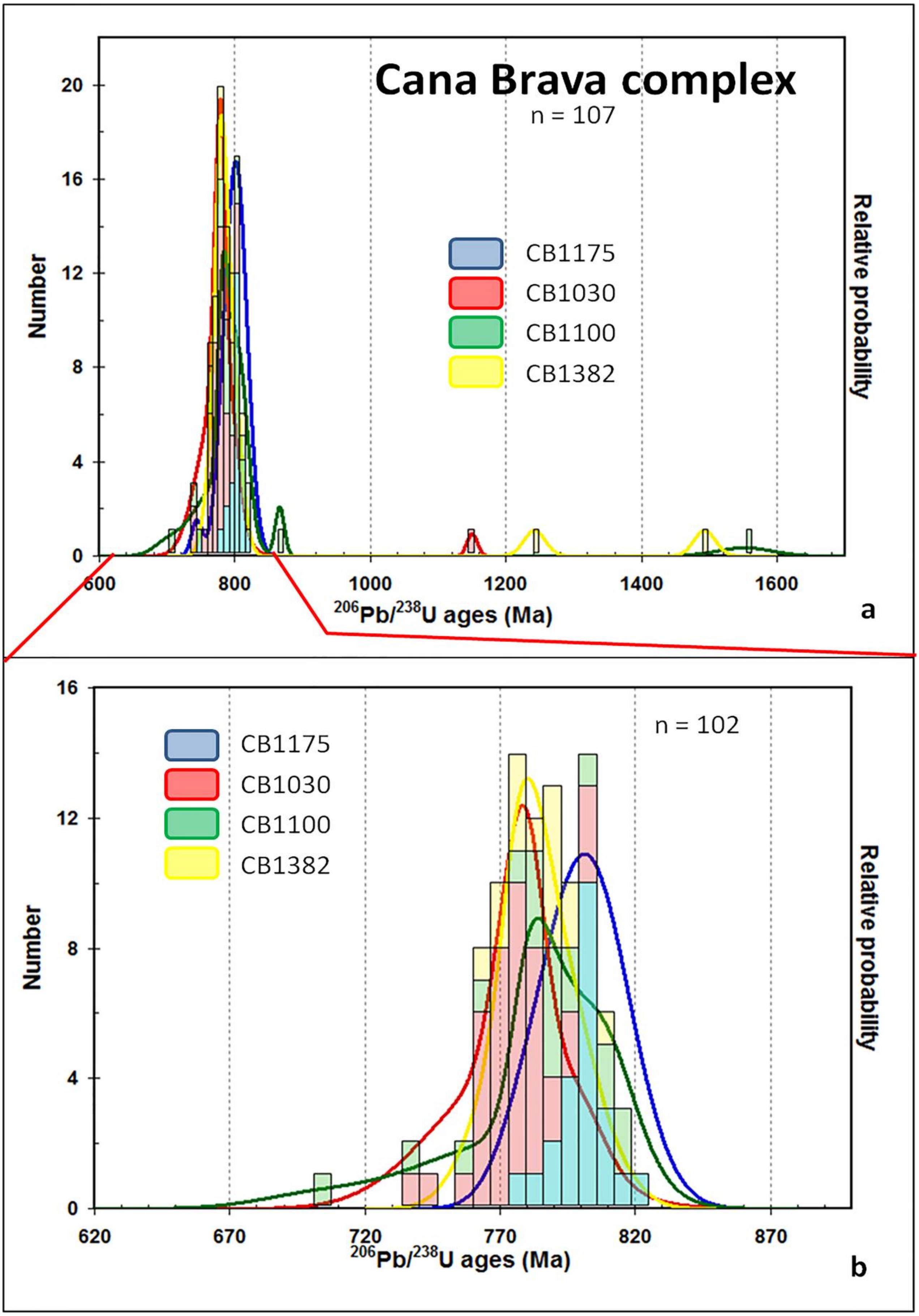

Cana Brava complex
n = 107
20
16
12
8
4
0
Number
CB1175
CB1030
CB1100
CB1382
Relative probability
600
800
1000
1200
1400
1600
206Pb/238U ages (Ma)
a
16
12
8
4
0
Number
n = 102
CB1175
CB1030
CB1100
CB1382
Relative probability
620
670
720
770
820
870
206Pb/238U ages (Ma)
b

Figure 12

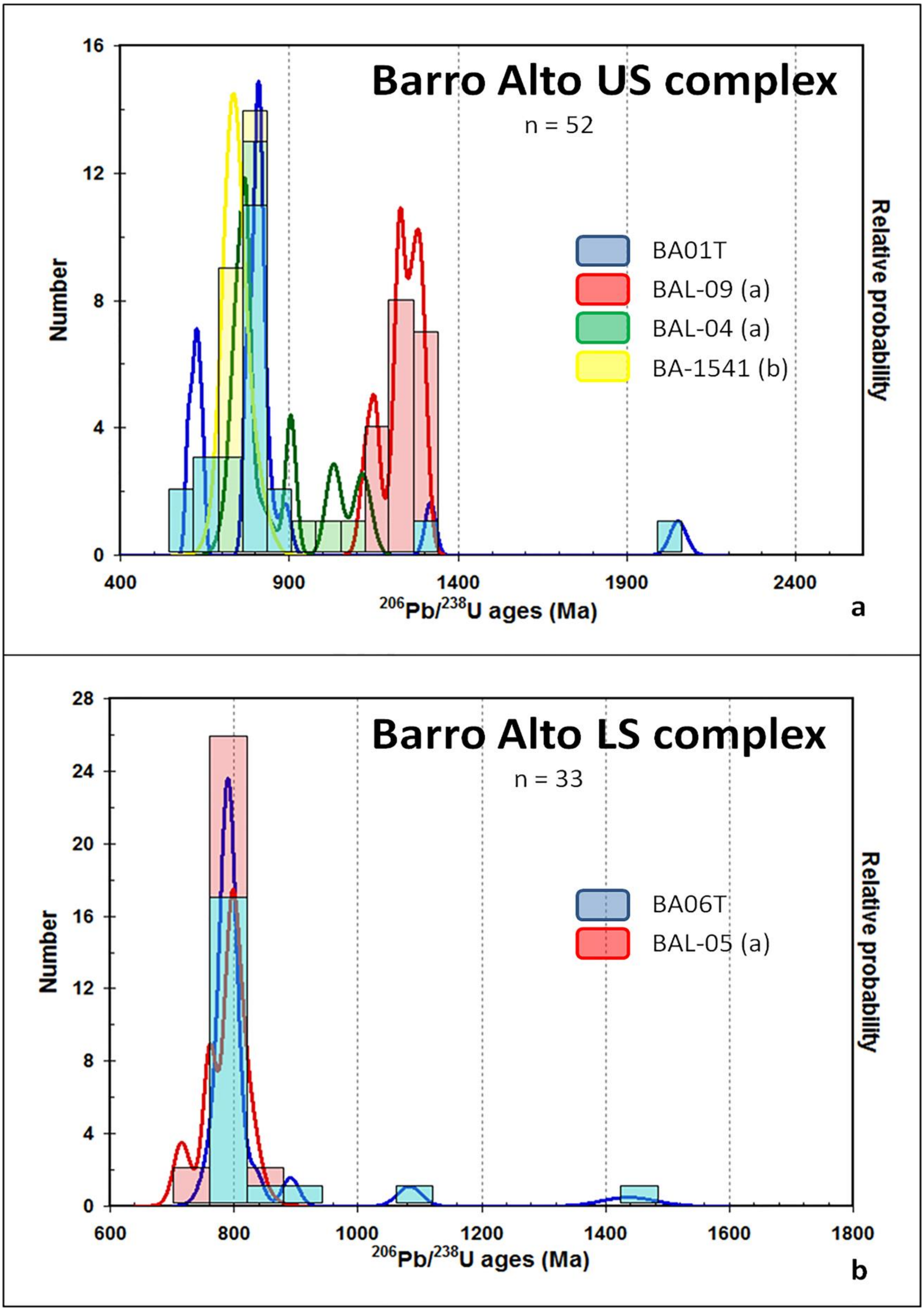
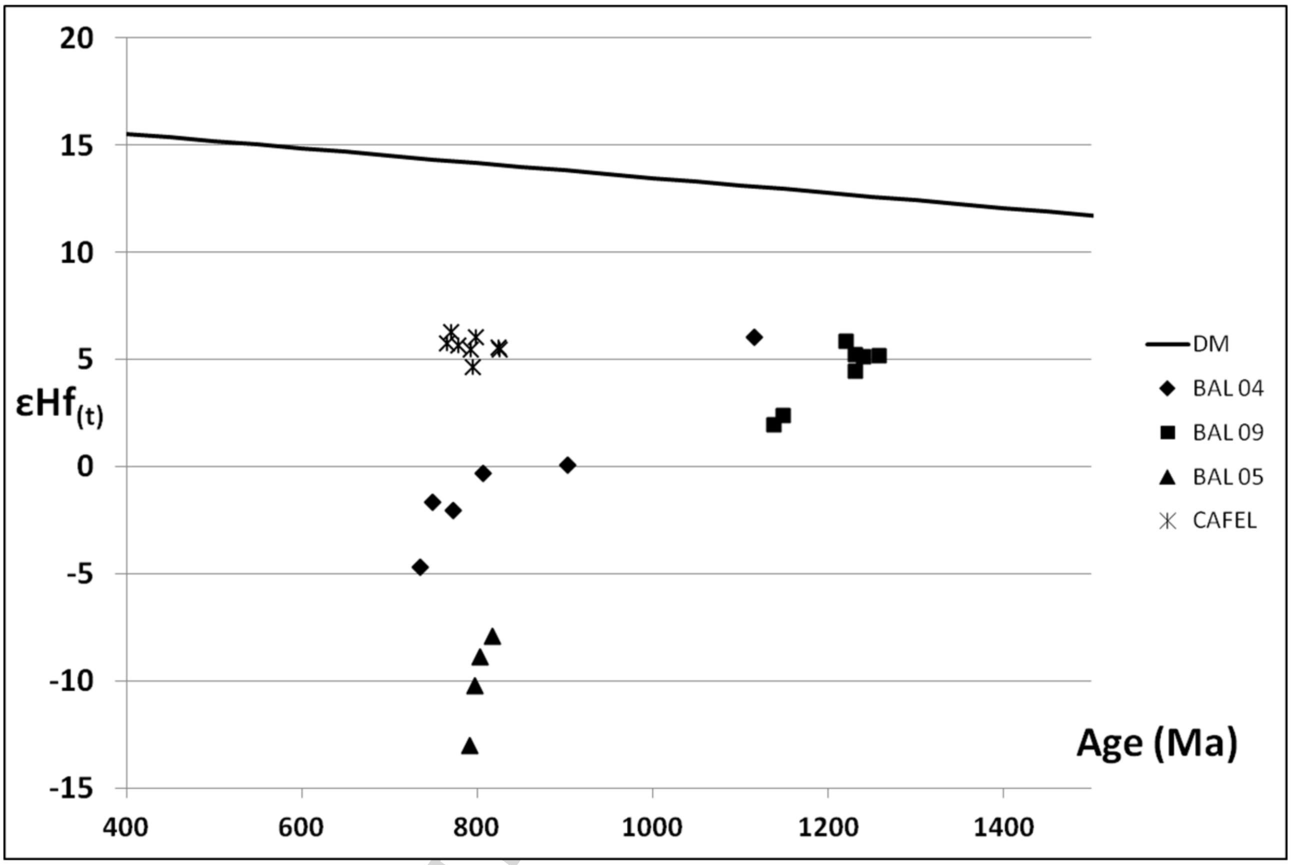

Barro Alto US complex
n = 52
BA01T
BAL-09 (a)
BAL-04 (a)
BA-1541 (b)
Number
Relative probability
0
4
8
12
16
400
900
1400
1900
2400
$^{206}Pb/^{238}U$ ages (Ma)
a
Barro Alto LS complex
n = 33
BA06T
BAL-05 (a)
0
4
8
12
16
20
24
28
600
800
1000
1200
1400
1600
1800
b

Figure 13



20
15
10
5
0
-5
-10
-15
εHf(t)
400
600
800
1000
1200
1400
Age (Ma)
DM
BAL 04
BAL 09
BAL 05
CAFEL

Figure 14

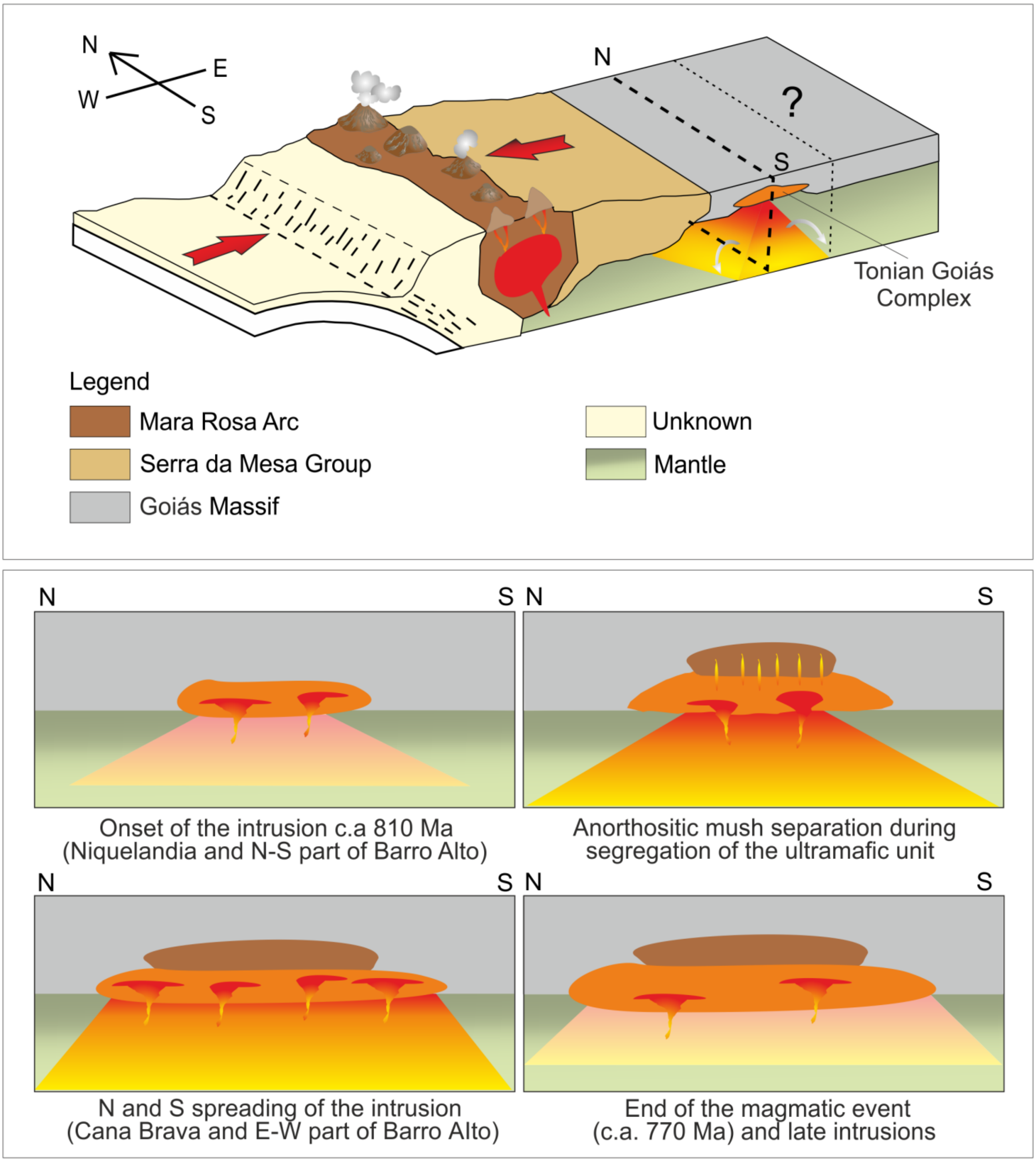

N
E
W
S
N
?
S
Tonian Goiás Complex
Legend
Mara Rosa Arc
Serra da Mesa Group
Goiás Massif
Unknown
Mantle
N
S
N
S
Onset of the intrusion c.a 810 Ma
(Niquelandia and N-S part of Barro Alto)
Anorthositic mush separation during
segregation of the ultramafic unit
N
S
N
S
N and S spreading of the intrusion
(Cana Brava and E-W part of Barro Alto)
End of the magmatic event
(c.a. 770 Ma) and late intrusions

Figure 15

Table 1: comparing of the Goiás literature stratigraphy.

<table>
<tr><td>Complex</td><td colspan="2">Barro Alto</td><td colspan="2">Niquelândia</td><td colspan="2">Cana Brava</td><td colspan="2">Common stratigraphic units</td></tr>
<tr><td>References</td><td>Ferreira Filho et al. (2010)</td><td>This work</td><td>Ferreira Filho et al. (2010)</td><td>Correia et al. (2012)</td><td>Ferreira Filho et al. (2010)</td><td>Giovanardi et al. (2015)</td><td colspan="2">This Work</td></tr>
<tr><td rowspan="7">Units</td><td rowspan="2">Serra da Malacheta Complex</td><td rowspan="2">Upper Gabbro Anorthosite Zone</td><td rowspan="2">Serra dos Borges Complex</td><td>Upper Amphibolites</td><td rowspan="2">Missing</td><td rowspan="2">Missing</td><td rowspan="2">Upper Sequence</td><td rowspan="2">Upper Gabbro Anorthosite Zone</td></tr>
<tr><td>Upper Gabbro Anorthosite Zone</td></tr>
<tr><td rowspan="2">Not recognized in the field</td><td rowspan="2">Mafic Zone</td><td rowspan="2">Upper Mafic Zone</td><td>Hydrous Zone</td><td rowspan="2">Upper Mafic Zone</td><td>Upper Layered Gabbro Unit</td><td rowspan="5">Lower Sequence</td><td rowspan="2">Mafic Zone</td></tr>
<tr><td>Layered Gabbro Zone</td><td>Lower Layered Gabbro Unit</td></tr>
<tr><td rowspan="2">Ultramafic Zone</td><td rowspan="2">Ultramafic Zone</td><td rowspan="2">Ultramafic Zone</td><td>Layered Ultramafic Zone</td><td rowspan="2">Ultramafic Zone</td><td>Cumulitic Websterite Unit</td><td rowspan="2">Ultramafic Zone</td></tr>
<tr><td>Basal Peridotite Zone</td><td>Ultramafic Unit</td></tr>
<tr><td>Lower Mafic Zone</td><td>Lower Mafic Zone</td><td>Lower Mafic Zone</td><td>Basal Gabbro Zone</td><td>Lower Mafic Zone</td><td>Basal Unit</td><td>Lower Mafic Zone</td></tr>
</table>

Table 2: summary of literature U-Pb ages (Ma) of the Goias complexes and ages of the metavolcanic-metasedimentary sequences.

Reference	Barro Alto		Niquelândia		Cana Brava	Metavolcanic-metasedimentary Sequence
	LS	US	LS	US		
Ferreira Filho et al. 1994			794 ± 6			
Suita et al. 1994	780	1235-1290 820-770				1730-1720 1266 ± 17
Araujo et al. 1996						1170–1270
Correia et al. 1999						1299 ± 3
Pimentel et al. 2004			797 ± 10	1248 ± 23		
Moraes et al. 2006						1277 ± 15 1263 ± 15
Pimentel et al. 2006			799 ± 6			
Correia et al. 2007		733 ± 25		833 ± 21		
Ferreira Filho et al. 2010					782 ± 3 779 ± 1	1242 ± 92
Della Giustina et al. 2011	774 ± 67	1288 ± 14 1271-720				
Correia et al. 2012				781 ± 4		
Giovanardi et al. 2015					792 ± 9 778 ± 7	

Tab. 3: SHRIMP-II analyses on zircons from Cana Brava complex and ages.

Sample	U (ppm)	Th (ppm)	Ratios						Ages (Ma)								
			$^{206}Pb/^{207}Pb$	1σ (%)	$^{207}Pb/^{235}U$	1σ (%)	$^{206}Pb/^{238}U$	1σ (%)	$^{206}Pb/^{207}Pb$	2σ	$^{207}Pb/^{235}U$	2σ	$^{206}Pb/^{238}U$	2σ	Conc.	2σ	% disc.
CB1 175																	
1.1	171	47	0.066356	2.4	1.21504	3.2	0.132806	2.1	818	102	808	18	804	31	808	16	2
1.2	381	193	0.065452	1.0	1.20365	2.1	0.133377	1.8	789	40	802	12	807	28	802	11	-2
2.1	1382	1748	0.065391	0.5	1.20414	1.9	0.133555	1.8	787	20	802	10	808	28	802	5	-3
3.1	1786	2640	0.065335	0.3	1.22030	1.8	0.135462	1.8	785	14	810	10	819	28	809	3	-4
4.1	432	336	0.067602	2.8	1.23372	3.4	0.132367	1.8	856	121	816	19	801	28	817	15	7
4.2	154	43	0.066380	4.5	1.20838	5.0	0.132040	1.9	818	192	804	28	799	29	805	16	2
5.2	1103	1404	0.065715	0.5	1.19469	1.9	0.131853	1.8	797	21	798	10	798	27	798	6	0
6.1	813	114	0.065347	0.6	1.18107	1.9	0.131084	1.8	786	24	792	10	794	27	792	7	-1
7.1	1962	3093	0.065644	0.5	1.19823	1.9	0.132386	1.8	795	21	800	10	801	27	800	6	-1
8.1	1746	2098	0.065277	0.4	1.19684	1.8	0.132976	1.8	783	15	799	10	805	27	799	4	-3
8.2	179	51	0.065121	3.9	1.19128	4.4	0.132690	1.9	778	166	797	24	803	29	796	15	-3
9.1	1693	2665	0.065792	0.3	1.19558	1.8	0.131797	1.8	800	15	799	10	798	27	799	4	0
10.1	1749	1586	0.065549	1.0	1.17811	2.1	0.130357	1.8	792	41	790	11	790	27	790	11	0
10.2	579	124	0.065528	0.6	1.20036	1.9	0.132857	1.8	791	27	801	11	804	28	800	8	-2
11.1	211	64	0.066380	1.8	1.19992	2.6	0.131106	1.9	818	78	801	15	794	28	801	14	3
11.2	1174	1280	0.065230	0.7	1.17452	2.0	0.130593	1.8	782	32	789	11	791	27	789	9	-1
12.1	321	229	0.066022	3.2	1.20571	3.8	0.132461	1.9	807	138	803	21	802	28	803	15	1
13.1	2278	3845	0.065262	0.4	1.19606	1.8	0.132919	1.8	783	15	799	10	804	27	798	4	-3
14.1	1266	1403	0.065582	0.4	1.19687	1.9	0.132361	1.8	793	17	799	10	801	27	799	4	-1

15.1	1747	2275	0.065596	0.4	1.21662	1.8	0.134517	1.8	794	15	808	10	814	28	808	4	-2
15.2	484	119	0.065728	0.6	1.21263	1.9	0.133805	1.8	798	26	806	11	810	28	806	8	-1
CB1030																	
7.1	721	107	0.065908	0.5	1.15114	0.9	0.126674	0.7	803	22	778	5	769	11	779	5	5
7.2	137	49	0.066145	1.1	1.17296	1.8	0.128613	1.4	811	48	788	10	780	20	789	10	4
8.1	243	151	0.064919	1.7	1.15815	1.9	0.129390	0.8	772	74	781	11	784	12	781	7	-2
8.2	539	90	0.065765	0.8	1.16502	1.1	0.128481	0.8	799	35	784	6	779	11	785	6	3
9.1	573	58	0.066449	1.5	1.17296	1.7	0.128027	0.8	821	64	788	9	777	11	789	6	6
10.1	266	60	0.065603	3.2	1.15865	3.4	0.128102	0.9	794	137	781	18	777	13	781	7	2
11.1	238	133	0.066000	1.6	1.17080	1.8	0.128660	0.8	806	65	787	10	780	12	787	7	3
12.1	970	124	0.078774	0.4	2.12084	0.9	0.195267	0.7	1166	19	1156	6	1150	15	1162	6	1
12.2	637	158	0.064882	0.7	1.15012	1.0	0.128565	0.7	770	31	777	6	780	11	777	6	-1
12.3	154	48	0.063921	1.9	1.12382	2.2	0.127517	0.9	739	83	765	12	774	13	764	7	-4
13.1	162	97	0.064513	1.7	1.13199	1.9	0.127263	0.9	758	70	769	10	772	13	768	7	-2
14.1	442	150	0.065705	0.7	1.17497	1.0	0.129696	0.8	797	28	789	6	786	11	789	6	1
14.2	512	111	0.065579	0.8	1.16546	1.1	0.128893	0.8	793	36	785	6	782	11	785	6	1
15.1	283	202	0.065361	1.2	1.15531	1.4	0.128198	0.8	786	50	780	8	778	12	780	6	1
16.1	560	100	0.065364	0.7	1.14540	3.2	0.127092	3.1	786	27	775	17	771	45	775	7	2
16.2	325	97	0.065425	1.0	1.14636	3.2	0.127080	3.0	788	43	776	17	771	44	776	13	2
17.1	813	113	0.065176	2.8	1.18870	4.1	0.132278	3.0	780	116	795	23	801	46	795	22	-3
17.2	387	123	0.066341	1.1	1.16857	3.2	0.127754	3.0	817	44	786	18	775	44	787	14	5
18.1	251	86	0.065863	5.5	1.17717	6.3	0.129628	3.1	802	231	790	35	786	45	790	24	2
18.3	422	99	0.064911	3.3	1.12185	4.5	0.125349	3.0	771	140	764	24	761	44	764	23	1
19.1	17	10	0.064	1.	1.121	3.	0.126	3.	748	6	764	1	769	4	76	1	-3

	5	2	182	5	34	4	714	1		3		8		4	3	7	
19.2	179	97	0.064610	4.4	1.13109	5.4	0.126968	3.1	762	1187	768	29	771	45	768	24	-1
19.3	380	37	0.064746	0.9	1.11630	3.2	0.125045	3.0	766	39	761	17	760	44	761	11	1
21.1	326	143	0.063368	1.5	1.10156	3.4	0.126078	3.1	721	64	754	18	765	44	753	16	-6
22.2	351	41	0.064873	2.0	1.12531	3.7	0.125807	3.0	770	86	766	20	764	44	766	20	1
23.1	554	159	0.065393	0.7	1.13530	3.2	0.125916	3.1	787	29	770	17	765	45	771	8	3
25.1	269	82	0.065413	1.1	1.15121	3.3	0.127641	3.1	788	46	778	18	774	45	778	14	2
26.1	781	160	0.065294	1.5	1.12020	3.4	0.124429	3.0	784	64	763	18	756	43	764	18	4
26.2	407	96	0.064653	1.2	1.14027	3.2	0.127913	3.0	763	49	773	18	776	44	772	14	-2
CB1 100																	
1.1	166	85	0.065059	2.3	1.15754	2.5	0.129042	0.9	776	98	781	14	782	14	781	7	-1
3.1	377	230	0.066491	0.9	1.17827	1.2	0.128524	0.8	822	40	791	7	779	11	791	6	5
4.1	227	131	0.072122	1.1	1.42994	1.4	0.143797	0.8	989	46	902	8	866	14			14
5.1	468	171	0.065375	1.0	1.16345	1.4	0.129074	1.1	786	40	784	8	783	15	784	8	0
7.1	248	71	0.081591	5.0	1.54328	5.1	0.137178	0.9	1236	196	948	31	829	15			49
8.1	155	61	0.065001	1.2	1.12488	3.3	0.125512	3.1	774	52	765	18	762	44	766	15	2
9.1	310	124	0.065885	0.9	1.18910	3.2	0.130897	3.0	803	40	796	18	793	45	796	12	1
10.1	174	122	0.065390	1.6	1.15716	3.5	0.128346	3.1	787	69	781	19	778	45	781	18	1
11.1	275	123	0.064573	1.3	1.16851	3.3	0.131245	3.0	760	53	786	18	795	46	785	15	-4
CB1 382																	
1.1	94	94	0.064365	2.9	1.13278	3.0	0.127645	1.0	754	121	769	16	774	15	769	8	-3
3.1	301	210	0.066025	4.0	1.18079	4.1	0.129717	0.8	807	169	792	23	786	12	791	6	3
3.2	246	143	0.066830	1.1	1.18787	1.4	0.128914	0.9	832	44	795	8	782	13	796	7	6
4.1	60	92	0.065	0.	1.153	1.	0.127	0.	788	2	779	5	776	1	77	5	2

6.1	6 17 6	15 0	409 0.065 080	6 2. 3	38 1.152 46	0 2. 5	890 0.128 437	7 0. 9	777	6 9 9	778	1 4	779	1 1 3	9 77 8	7	0

Tab. 4: SHRIMP-II analyses on zircons from Barro Alto complex and age.

			Ratios						Ages (Ma)								
Sample	U (ppm)	Th (ppm)	$^{206}Pb/^{207}Pb$	1σ (%)	$^{207}Pb/^{235}U$	1σ (%)	$^{206}Pb/^{238}U$	1σ (%)	$^{206}Pb/^{207}Pb$	2σ	$^{207}Pb/^{235}U$	2σ	$^{206}Pb/^{238}U$	2σ	Conc.	2σ	% disc.
BA01T																	
1.1	58	14	0.066060	3.5	1.21735	4.2	0.133653	2.3	808	146	809	23	809	35	809	24	-0
2.1	140	2	0.064502	2.2	1.19479	2.6	0.134343	1.4	758	92	798	14	813	21	797	15	-8
3.1	353	239	0.066032	0.8	1.20504	1.5	0.132357	1.3	807	35	803	9	801	19	803	8	+1
4.1	121	64	0.066332	2.8	1.20674	3.1	0.131944	1.5	817	117	804	17	799	22	804	18	+2
5.1	444	106	0.066039	1.3	1.22662	1.9	0.134712	1.3	808	56	813	10	815	20	813	10	-1
6.1	124	29	0.070324	2.8	1.43416	3.5	0.147908	2.0	938	116	903	21	889	33	904	21	+6
7.1	153	73	0.062832	2.1	0.88885	2.6	0.102601	1.4	703	91	646	12	630	17	647	13	+11
8.1	87	103	0.062686	3.4	0.88022	3.7	0.101841	1.5	698	144	641	18	625	18	642	18	+11
8.2	406	104	0.063102	2.9	0.84843	3.2	0.097515	1.4	712	122	624	15	600	16	625	15	+16
9.1	112	118	0.060622	3.1	0.83403	3.4	0.099782	1.5	626	134	616	16	613	17	616	16	+2
9.2	263	165	0.060889	1.9	0.88150	2.3	0.104998	1.3	635	83	642	11	644	16	642	11	-1
10.1	366	106	0.065679	1.0	1.21178	1.6	0.133811	1.3	796	41	806	9	810	20	806	9	-2
11.1	316	29	0.064989	1.7	1.16344	2.2	0.129838	1.5	774	72	784	12	787	22	783	12	-2
12.1	204	80	0.134147	0.9	4.19478	1.6	0.226792	1.3	2153	30	1673	13	1318	32	1687	13	+43
12.2	152	55	0.134672	0.7	6.95846	1.6	0.374745	1.4	2160	24	2106	14	2052	50	2108	14	+6

13.1	256	150	0.064677	1.5	1.13733	2.0	0.127537	1.3	764	64	771	11	774	20	771	11	-1
14.1	207	74	0.066042	1.8	1.24366	2.2	0.136578	1.4	808	74	821	13	825	21	820	13	-2
15.1	318	164	0.067479	1.4	1.29805	2.4	0.139515	2.0	853	59	845	14	842	31	845	14	+1
16.1	144	229	0.065347	2.7	1.14377	3.1	0.126943	1.5	786	113	774	17	770	21	775	17	+2
BA06T																	
1.1	461	236	0.066405	0.8	1.20548	1.7	0.131661	1.5	819	33	803	10	797	23	804	9	+3
2.1	1058	463	0.065590	0.5	1.18838	1.6	0.131407	1.5	793	20	795	9	796	23	795	9	-0
3.1	274	168	0.065149	1.2	1.16936	2.0	0.130179	1.6	779	49	786	11	789	23	786	11	-1
3.2	61	25	0.065019	3.9	1.16727	4.3	0.130206	1.9	775	164	785	24	789	27	785	24	-2
4.1	130	74	0.065733	1.8	1.17234	2.5	0.129351	1.7	798	77	788	14	784	25	788	14	+2
4.2	92	38	0.065206	3.9	1.12896	4.2	0.125572	1.7	781	162	767	23	763	25	767	23	+3
5.1	288	198	0.064713	1.3	1.16132	2.0	0.130155	1.6	765	55	783	11	789	23	782	11	-3
5.2	69	24	0.065322	4.5	1.16963	4.9	0.129863	1.8	785	189	786	27	787	27	786	27	-0
6.1	204	66	0.113906	3.5	3.92412	4.8	0.249858	3.4	1863	126	1619	39	1438	87	1626	39	+25
6.2	52	18	0.066613	3.8	1.21288	4.3	0.132057	1.9	826	160	807	24	800	28	807	24	+3
7.1	250	193	0.065620	1.2	1.16954	2.0	0.129264	1.6	794	49	786	11	784	23	787	11	+1
7.2	65	23	0.064329	5.3	1.11141	6.0	0.125305	2.7	752	225	759	32	761	38	759	33	-1
8.1	261	188	0.064753	1.3	1.16940	2.0	0.130978	1.6	766	53	786	11	793	24	786	11	-4
9.1	225	108	0.108989	0.7	2.75020	2.1	0.183012	2.0	1783	26	1342	16	1083	39	1356	15	+43
9.2	195	97	0.068132	1.3	1.39332	2.1	0.148320	1.6	873	52	886	12	892	27	886	12	-2
10.1	109	59	0.065030	2.9	1.17310	3.3	0.130834	1.7	775	121	788	18	793	25	788	19	-2
11.	15	89	0.067	3.	1.218	3.	0.130	1.	863	1	809	2	790	2	81	2	+9

1	2		833	1	55	5	287	6		29		0		4	0	0	
12.1	289	236	0.070235	0.8	1.34114	1.8	0.138492	1.6	935	32	864	10	836	25	866	10	+11
13.1	132	77	0.067356	1.7	1.24455	2.3	0.134009	1.7	849	69	821	13	811	25	822	13	+5
14.1	178	119	0.067385	1.6	1.20583	2.3	0.129784	1.6	850	66	803	13	787	24	805	13	+8
15.1	83	32	0.065725	3.7	1.17904	4.1	0.130106	1.7	798	155	791	22	788	26	791	23	+1

Highlights

The Goias layered mafic-ultramafic complexes intruded between 770-800 Ma;
The complexes are fragments of a larger complex, the Tonian Goias Stratiform Complex;
The Tonian Goias Stratiform Complex intruded under shear conditions;
The intrusion occurred in a back-arc setting related to the Goias Magmatic Arc;
The Tonian Goias Stratiform Complex was disrupted during its exhumation at 600-650 Ma;