Research Article


U-Pb zircon SHRIMP data from the Cana Brava layered complex: new constraints for the mafic-ultramafic intrusions of Northern Goiás, Brazil

DOI 10.1515/geo-2015-0015

Received March 18, 2014; accepted October 15, 2014

Abstract: The Cana Brava Complex is the northernmost and least well known layered intrusion of a discontinuous belt of mafic-ultramafic massifs within the Brasilia Belt, which also comprises the Niquelândia and Barro Alto complexes. Available geochronological data from a range of techniques (K/Ar, Ar/Ar, Rb/Sr, Sm/Nd and U/Pb) provide a range of possible ages (time span from 3.9 Ga to 450 Ma), hence a precise and reliable age for the Cana Brava Complex is still lacking. Also, preliminary isotopic and geochemical data of the Cana Brava Complex suggest a significant crustal contamination, which could have affected bulk-rock Sr and Nd systematics resulting in meaningless age determinations. In this paper, we present new U-Pb SHRIMP zircon analyses from four samples of different units of the Cana Brava Complex which suggest that the intrusion occurred during the Neoproterozoic, between 800 and 780 Ma, i.e. at the same age of Niquelândia. Discordant older 206Pb/238U ages are provided by inherited zircons, and match the age of the metamorphism of the embedding Palmeirópolis Sequence.

Keywords: Cana Brava; Layered Complex; Geochemistry; Zircon; SHRIMP

1 Introduction

The Cana Brava mafic-ultramafic complex is the northernmost layered intrusion of a discontinuous belt of mafic-ultramafic massifs which also comprises the Barro Alto Complex in the south and the Niquelândia Complex in the central sector. The mafic-ultramafic belt is oriented North-South, about 300 km long, and considered part of the central-eastern Brasilia Belt [1, 2]. It is included by Pimentel et al. [3] in the Maciço Mediano do Goiás (i.e. the Goiás Massif).

The Niquelândia mafic-ultramafic complex is relatively well-known [4–10], whereas the others two complexes of the Brasilia Belt (i.e. Cana Brava and Barro Alto) are still poorly studied. Correia et al. [9, 10] and Rivalenti et al. [5] demonstrated that the Niquelândia Complex underwent a strong crustal contamination by a metasedimentary component, which affected the whole rock geochronological data obtained by Rb/Sr, Sm/Nd and K/Ar isotopic systematics (see [11], for the treatment and the significance of whole rock geochronological data in cases of open system: e.g. crustal contamination). Hence, age estimates provided by whole rock Rb/Sr, Sm/Nd, Ar/Ar and K/Ar analyses [1, 2, 12, 13] as well a whole rock + plagioclase + biotite + pyroxene Sm/Nd internal isochrons [2] should be largely disregarded. Correia et al. [2], on the basis of Rb/Sr and Sm/Nd isotope geochemistry, suggested that the Cana Brava Complex underwent extensive crustal contamination, similarly to the Niquelândia Complex.

In this paper, we present new SHRIMP U-Pb zircon analysis with the aim of providing new constraints on the Cana...
Brava intrusion age, as recently done for the Niquelândia Complex, by Correia et al. [10].

2 Geological setting

The Cana Brava Complex (Figure 1) is about 40 km long and 14 km wide (the widest portion located in the south). The Cana Brava Complex main strike is 10°–20° NNE and dip 30° to 50° NW [14]. The base of the complex is located in the east and the top to the west. The Cana Brava Complex is overthrust to the east on the metasedimentary rocks of the Serra da Mesa Group, while, in the west, it is in magmatic contact with the metasedimentary and metavolcanic rocks of the Palmeirópolis Sequence [2, 14, 15]. The igneous nature of the roof contact is supported by the presence, in the upper units of the complex, of septa and lenses of amphibolites of the Palmeirópolis Sequence [2, 14] and by the absence of mylonites near the contact [14]. According to Correia [14] the Cana Brava mafic-ultramafic Complex is divided, from the base to the top, into 5 units. Correia [14] used the acronym PICB (Proterozoic Inferior Complex) for the all the different units. Here, the units are re-named on the basis of new chronostratigraphic criteria, and to make an easier comparison with the other complexes of the Brasilia Belt. The modified stratigraphic units are:

1. Basal Unit (BU), (corresponding to PICB1 of Correia [14]), which includes intercalated gabbros and epidote-bearing amphibolites with locally mylonitic texture;
2. Ultramafic Unit (UU) (corresponding to PICB2 of Correia [14]), which consists of largely serpentinized peridotite cumulates;
3. Cumulus Websterite Unit (CWU) (corresponding to PICB3 of Correia [14]), constituted by massif websterite with cumulus textures;
4. Lower Layered Gabbro Unit (LLGU) (corresponding to PICB4 of Correia [14]), formed by layered gabbros;
5. Upper Layered Gabbro Unit (ULGU) (corresponding to PICB5 of Correia [14]), which comprises gabbros and more differentiated lithologies approaching the top.

A more detailed description of the rocks of the Cana Brava Complex is reported in Correia [14] and a brief summary of the units names is given in Table 1. Correia et al. [2] reported the common occurrence of shear zones, faults and deformations in all the units of the Cana Brava Complex. In general, as described in the Niquelândia Complex by Correia et al. [10], these structures are parallel to the primary igneous foliation. The most important shear zone reported by Correia et al. [2] occurs at the transition between the LLGU and ULGU in the southern portion of the complex (Corrego Verde Shear Zone). Xenoliths of the enclosing Palmeirópolis Sequence have been found within both the LLGU and ULGU. According to Correia et al. [2], the xenoliths are schist, quartzite and amphibolite, showing a complex metamorphic foliation, which were incorporated and transposed parallel to the gabbro foliation. Commonly, the xenoliths show reaction rims with the host gabbro, with the appearance of high-grade contact metamorphic assemblages (i.e. orthopyroxene - garnet - rutile; [2]).

Several episodes of recrystallization were inferred in the Cana Brava Complex. Girardi & Kurat [15] proposed three different events: i) a granulite facies metamorphism or a sub-solidus re-equilibration during slow cooling, which took place at about 900°C and 6-7 kbar; ii) next, an event of upper-amphibolite facies metamorphism, responsible for the formation of amphibole at the expense of clinopyroxene; iii) a final low-temperature event which generated serpentinite, rodingite, and talc schist. On the basis of the Rb/Sr and Sm/Nd whole-rock ages and a Sm/Nd internal isochron, Correia et al. [2] proposed for the Cana Brava Complex three different events of recrystallization, the first and the last of which are comparable to those inferred by Girardi & Kurat [15] and the intermediates would be related to the Uruaçuano Cycle and the Brasiliano orogeny [16]. The three major intrusions of the Brasilia Belt (i.e., from south to north, Barro Alto, Niquelândia and Cana Brava) shear similar features which are commonly interpreted as fragments of a single continuous structure [3, 17]. According to Pimentel at al. [3], Ferreira Filho et al. [17] and Moraes et al. [18] the tholeiitic-MORB geochemical affinity [1–6] of the three complexes is consistent with a rift environment during the early stages of continental rifting up to the formation of an ocean basin.

3 Previous geochronological data

Two Ar-Ar whole-rock isochrons yielded ages of 1935±110 Ma and 475±15 Ma [12]. Matsui et al. [12] provided also several K-Ar ages which are distributed over a wide time span from 3950 Ma to 480 Ma. Girardi et al. [1] report a Rb-Sr whole-rock isochron age at 1157±150 Ma, obtained on samples of gneiss, schist and calc-silicate rock of the Palmeirópolis Sequence from the western border. At the eastern border the complex is in tectonic contact with
Figure 1: Geological map of the Cana Brava Complex, modified after Correia et al. [2].

Table 1: New names and acronyms of the Cana Brava Complex units and comparison with the old unit names from Correia [14].

<table>
<thead>
<tr>
<th>Cana Brava Complex Units</th>
<th>This study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proterozoic Inferior Cana Brava 1 (PICB1)</td>
<td>Basal Unit (BU)</td>
</tr>
<tr>
<td>Proterozoic Inferior Cana Brava 2 (PICB2)</td>
<td>Ultramafic Unit (UU)</td>
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<td>Cumulus Websterite Unit (CWU)</td>
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<td>Lower Layered Gabbro Unit (LLGU)</td>
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<tr>
<td>Proterozoic Inferior Cana Brava 5 (PICB5)</td>
<td>Upper Layered Gabbro Unit (ULGU)</td>
</tr>
</tbody>
</table>
gnephises which yielded a younger whole-rock isochron age of 644±27 Ma. Girardi et al. [1] interpreted the two ages as two different metamorphic peaks which induced the re-crystallization of these rocks in amphibolite facies conditions.

Whole rock Sm-Nd isochrons obtained by Fugi [13] for the Cana Brava Complex and the Serra da Bota Gabbro (a smaller gabbro body located close to the eastern contact of Cana Brava within the Serra da Mesa group) yielded ages of 1970±69 Ma and 1088±18 Ma, respectively, which were interpreted as intrusion ages. Whole-rock Rb-Sr determinations and a Sm-Nd internal isochron on whole rock and plagioclase + biotite + pyroxene were performed by Correia et al. [2]. The whole-rock Rb-Sr isochron points to an “age” of 1350±35 Ma while the Sm-Nd internal isochron results in a younger age (770±43 Ma). Correia et al. [2] calculated the regression of the Sr isotopic evolution curve of the Cana Brava Complex, obtaining a minimum age at 2.25 Ga, which was interpreted as the time of the Cana Brava intrusion, whereas the oldest and the youngest ages (i.e. 1350±35 Ma and 770±43 Ma) were attributed to metamorphic events. However, all these data are artefacts of mixing of mantle- and crust- derived components and whole rock data of these hybrid rocks are questionable and should be disregarded. The effects of crustal contamination in the Cana Brava Complex are described by Correia et al. [2] and Ferreira Filho et al. [17].

Ferreira Filho et al. [17] determined U-Pb TIMS zircon ages on two samples from the ULGU and (probably) UU (four and three analyses, respectively). Both samples provide Neoproterozoic ages at 782±3 Ma and 779±1 Ma which are interpreted as intrusion ages of the complex. This is the most reliable age determination as far.

4 Samples and analytical methods

Zircons were separated after crushing, milling, magnetic and heavy liquid separation and hand-picking from 4 samples of the Cana Brava Complex. Out of four samples, one sample (CB1175) is from quartz gabbro at the top of the LLGU while the others (CB1030, CB1100 and CB1382) are representative samples from quartz gabbros of the ULGU [13, 18]. All these rocks show granoblastic texture and zircons occur as accessory phases. The modal composition of the samples, reported by Correia [14], is reported in Table 2.

After the Au-coating, the polished 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 emission current, 15.0 kV accelerating voltage, 7 µm beam diameter, 200 µs acquisition time, and a resolution of 1024×884 dpi. U-Th-Pb isotopic ratios and elemental abundances in ca. 20 µm diameter areas of zircons were determined using the SHRIMP II at the Western Australia Isotope Science Research Centre, Curtin University of Technology, Perth. A 2.0 nA primary ionizing O²⁻ beam was employed, and mass resolution set at 5000, resulting in a sensitivity for Pb isotopes of 15 counts per second per Pb ppm per nA. Pb isotope ratios were corrected for common Pb on the basis of the measured ²⁰⁶Pb/²⁰⁸Pb, typically resulting in a <1% correction to ²⁰⁶Pb. Pb/U isotope ratios were corrected for the interelement discrimination using data currently obtained from the Perth standard zircon CZ3 (²⁰⁶Pb/²³⁸U = 0.0914). Ages were calculated using standard decay constants. A more detailed description of the methodology is reported in Correia [19].

3 zircons were analyzed from sample CB1175, 19 zircons from sample CB1100, 12 zircons each from samples CB1030 and CB1382. Analyses are reported in Table 3.

5 Zircon morphology

Zircons separated from sample CB1175 (LLGU) show commonly anhedral-to-subhedral habit. Zircons are colourless and CL images show extremely complex structures (Figure 2A) with complex and chaotic oscillatory zoning and domains, often superimposed by other structures and sometimes partially deleted. Such zoning can indicate deep resorption of the early zircon phase and, possibly, a new zircon growth in a different crystallographic orientation than the substrate zircon [20].

Zircons from ULGU samples show subhedral-to-anhedral habit. Zircons are colourless. CL images commonly show cores with oscillatory zoning or different brightness domains (Figure 2B, C, D). Sometimes the core shows local recrystallization and/or local intermediate resorption. Often the cores are rounded with truncated internal zoning caused by superimposed accretion with different growths of oscillatory zoning (Figure 2B, D). Sometimes the new growth on cores shows domains of variable width and are occasionally resorbed (Figure 2B, D). Some crystals show continuous and simple overgrowth without any accretion structure (Figure 2C).
Figure 2: Cathodoluminescence imaging of analyzed zircons from each sample with different structures. In particular, zircon CB1175 (A) shows complex structure; CB1030 (B) shows a magmatic core and two stages of overgrowth rims; CB1382 (C) shows a single zoning growth; CB1100 (D) shows a magmatic core and a single stage of overgrowth rim.

Table 2: Modal composition of rocks from Correia [14].

<table>
<thead>
<tr>
<th>Sample</th>
<th>CB1175</th>
<th>CB1030</th>
<th>CB1100</th>
<th>CB1382</th>
</tr>
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<tbody>
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<td>ULGU</td>
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<td>19.0</td>
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<td>2.6</td>
<td>2.4</td>
<td></td>
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<tr>
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<td>18.0</td>
<td>51.2</td>
<td>42.3</td>
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<tr>
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<td>43.0</td>
<td>5.0</td>
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</tr>
<tr>
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<td>10.0</td>
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<td>193</td>
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<td>CB1100</td>
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<td>145</td>
<td>60</td>
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</table>

Table 3: U-Pb isotopic data and ratios and $^{206}$Pb/$^{238}$U ages (Ma).
6 Geochronological U-Pb data

$^{206}$Pb/$^{238}$U and $^{207}$Pb/$^{235}$U concordia ages, with 95% of confidence level and 2σ error, are calculated using Isoplot software [21] for all samples (Figure 3A, B, C, D).

Only 3 zircons were analyzed on sample CB1175, and one of them (n. 133) was rejected because high U. The two analyses provide a concordia age of 778.0±6.7 Ma (Figure 3A), with MSWD = 0.43 and probability of concordance = 0.51. $^{207}$Pb/$^{206}$Pb ratio varies from 0.0634 to 0.0647, $^{206}$Pb/$^{238}$U from 0.1278 to 0.1292 and $^{207}$Pb/$^{235}$U from 0.940 to 1.153 (Table 3).

12 zircons from sample CB1030 show $^{207}$Pb/$^{206}$Pb ratio from 0.0559 to 0.0725, $^{206}$Pb/$^{238}$U from 0.1219 to 0.1325 and $^{207}$Pb/$^{235}$U from 0.940 to 1.312 (Table 3). The calculated concordia age is 783.1±8.5 Ma, with MSWD = 1.8 and probability of concordance = 0.18 (Figure 3B).

12 spot analyses were performed on sample CB1382. Disregarding analyses 41 and 44 because they are clearly inherited cores, providing $^{206}$Pb/$^{238}$U ages older than 1.2 Ga, the remaining 10 analyses provide a concordia age of 787.0±8.3 Ma (Figure 3C; MSWD = 0.15 and probability of concordance = 0.70). The CB1382 crystals have $^{207}$Pb/$^{206}$Pb ratios...
from 0.0557 to 0.0672, $^{206}\text{Pb}/^{238}\text{U}$ from 0.1251 to 0.1340 and $^{207}\text{Pb}/^{235}\text{U}$ from 0.960 to 1.220 (Table 3).

12 spot analyses from sample CB1100 provide a concordia age of 791.9 ± 9.1 Ma (Figure 3D), with MSWD = 2.9 and probability of concordance = 0.09. The $^{207}\text{Pb}/^{206}\text{Pb}$ ratio varies from 0.0631 to 0.0701, $^{206}\text{Pb}/^{238}\text{U}$ from 0.1152 to 0.1346 and $^{207}\text{Pb}/^{235}\text{U}$ from 1.043 to 1.301 (Table 3). Analysis 72 is excluded because is an inherited zircon which provides a $^{206}\text{Pb}/^{238}\text{U}$ age of 1552 Ma, analyses 77 and 85 were excluded because largely discordant. Finally, analyses 51, 57, 73 and 74 were excluded because of the low U abundance. Combining all data, excluding those rejected, the results gave a concordia age of 788 ± 2.1 Ma (MSWD = 0.65 and probability of concordance = 0.42, Figure 4). In the probability density distribution of the $^{206}\text{Pb}/^{238}\text{U}$ ages (Fig. 5), the ages concentrated between 800-780 Ma, with few analyses near 760 Ma.

Notwithstanding that most analyses point to Neoproterozoic ages, a few spot $^{206}\text{Pb}/^{238}\text{U}$ ages from samples CB1100 (1 analysis) and CB1382 (2 analyses) provided older ages suggesting they are inherited from the host rock. These zircons are discordant, which suggests that they were affected by Pb loss. Calculated $^{206}\text{Pb}/^{238}\text{U}$ ages provide three peaks at 1552 Ma, 1493 Ma and 1242 Ma (Figure 5). Also, younger $^{206}\text{Pb}/^{238}\text{U}$ spot ages were found in accretion rims of some crystals in each sample (758-703 Ma), suggesting late stages of Pb-loss or resetting/zircon growth (Figure 5).

7 Discussion

Among the three mafic-ultramafic massifs of the Goiás Massif, the Niquelândia Complex is the most studied. Pimentel et al. [7, 8] proposed that the Niquelândia Complex comprises two separate intrusions on the basis of the presence of deformation structures between the Upper Complex (UC) and the Lower Complex (LC), i.e. the pervasive presence of NS-N10E ductile shear zones with well-developed tectonic foliation within areas where completely or dominantly primary igneous textures are observed [22]. Based on SHRIMP U-Pb zircon ages and a Sm-Nd internal isochrons, these authors attributed to LC and UC crystallization ages of 797±10 Ma and to 1248±23 Ma respectively. However, according to Girardi et al. [6], Correia et al. [9], Rivalenti et al. [5] the two units belong to a single complex, with a gradational contact represented by the Hydrous Zone (HZ) and the differences between the two units are related to the different conditions of the same intrusion. This hypothesis was initially supported by SHRIMP U-Pb zircon ages obtained by Correia et al. [9] from an anorthosite at the top of UC (sample Niq1552) which provided a crystallization age of 833±21 Ma. Recently, Correia et al. [10] demonstrated that LC and UC are part of the same Neoproterozoic intrusion on the basis of a SHRIMP U-Pb age of 780.8±3.7 Ma on zircons from another anorthosite sample (Niq1551) from UC. This age is similar to the intrusion age (within errors) of the LC proposed by Pimentel et al. [7, 8]. Also, the age of 1248±23 Ma interpreted by Pimentel et al. [7, 8] as the intrusion of the UC, was provided by a gabbro affected by significant inheritance, as described by the same authors and discussed by Correia et al. [10]. Moreover, this Mesoproterozoic age is similar to U-Pb and Sm-Nd ages obtained by Moraes et al. [18] for the Juscelândia Sequence and other samples of the volcano-sedimentary country-rocks of Cana Brava and Niquelândia. Furthermore, in the field there is no evidence of a tectonic contact (i.e. milonite or shear zone bands) between LC and UC. Based on these data and observations, Correia et al. [10] concluded that the Niquelândia Complex intruded in the volcano-sedimentary Sequence of Ivinhém at ca. 790 Ma. The Barro Alto Complex is less well studied than Niquelândia. Suita et al. [23] reported U-Pb zircon and monazite ages for different rocks from Barro Alto and the associated Juscelândia metavolcanic-metasedimentary Sequence. Obtained ages span from 1730-770 Ma, with peaks at 1.72 Ga, 1.35-1.29 Ga and 820-770 Ma [23]. Suita et al. [23] interpreted that the 1.73-1.72 Ga age is the intrusion time and the others are ages of metamorphic peaks. Correia et
al. [24] reported SHRIMP U-Pb ages, from rocks of meta
volcano-sedimentary sequence (acid granulite formed by
quartz + cordierite + sillimanite + plagioclase + mesoper-
tite near the western contact of the complex) and a high
grade metagranite, at 1286±13 Ma and 1302±32 Ma, respec-
respectively. Correia et al. [9] reported SHRIMP U-Pb zircon ages
between 799-726 Ma for the Barro Alto Complex. They sug-
that the Barro Alto intrusion occurred at 733±25 Ma, and
that the older ages obtained by Correia et al. [24] are
inherited from the country rocks. The U-Pb zircon ages pre-
sented in this paper for the Cana Brava Complex provide
further evidence for a Neoproterozoic intrusion. In partic-
sular, the ages obtained on four samples are undistinguish-
able within errors (791.9±9.0 Ma, 783.1±8.5 Ma, 787.0±8.3
Ma and 778.0±6.7 Ma for samples CB1100, CB1030, CB1382
and CB1175 respectively). The concordia age obtained pool-
ting together all analyses (beside those rejected) provides
an age at 788.0±2.1 Ma. The probability plot (comprising
the excluded data, Figure 5) shows a single peak around
800-780 Ma, with three inherited, older zircons and a mi-
nor peak shifted towards younger ages, a possible arte-
fact of later resetting/recrystallization event(s). The con-
cordia age around 788.0±2.1 Ma, is close to the age ob-
tained by Ferreira Filho et al. [17] on two samples of the
Cana Brava Complex (782±3 Ma and 779±1 Ma), is inter-
preted as intrusion ages, and is similar to the Sm/Nd inter-
nal isochron age of 770±43 Ma [2]. These ages are similar to
the U-Pb zircon ages interpreted as dating the intrusion of
Barro Alto [24], and Niquelândia [9, 10]. The few older spot-
ages are conceivably obtained on zircons inherited from
the country rocks. This hypothesis is also supported by the
crustal contamination of the Cana Brava Complex as sug-
gested by Correia et al. [2] and Ferreira Filho et al. [17], simi-
larly to that occurring in the Niquelândia Complex [9, 10].
Notwithstanding some U-Pb zircon ages of the Cana Brava
Complex are now available (Ferreira Filho et al. [17]; this
study), further analyses are required to provide a statisti-
cally supported data set for the determination of the Cana
Brava intrusion age.

8 Conclusion

The new U-Pb SHRIMP analyses on zircons from samples
of the Cana Brava Complex provide a concordia age of
788.0±2.1 Ma. Considering the analyzed samples individu-
ally, the $^{206}Pb/^{238}U$ age distribution suggests that the Cana
Brava Complex intruded the Palmeirópolis Sequence be-
tween 800-780 Ma. This age for the Cana Brava intrusion
is similar to those reported in literature for the intrusions
of the Niquelândia and Barro Alto complexes [9, 10, 24].
The similarity in the intrusion ages of the three complexes
points to a large igneous event in the region during the
Neoproterozoic. The presence of older and discordant zir-
cons suggests inheritance from the country rocks in the
Cana Brava Complex, as already observed in Niquelândia
by Correia et al. [10]. The effects of crustal contamination,
well-documented in Niquelândia [5, 10] and inferred for
the Cana Brava Complex too, suggest caution in interpret-
ing ages estimated by whole rock K/Ar, Ar/Ar, Sm/Nd and
Rb/Sr systematics. Nonetheless, further field work and U-
Pb zircon analyses are needed to give a larger statistical
support for the Cana Brava intrusion age and related geo-
logical events.

Acknowledgement: We are very grateful to the Research
Support Foundation of the State of São Paulo (FAPESP)
and to the National Brazilian Research Council (CNPq)
for financial support (FAPESP projects 97/00640-5 and
2011/50307-0, CNPq project PRONEX 41.96.0899.00).

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