New geological and single-zircon Pb evaporation data from the Central Guyana Domain, southeastern Roraima, Brazil: Tectonic implications for the central region of the Guyana Shield

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ARTICLE INFO

ABSTRACT

Metagranitoid rocks, mylonites, leucogneisses and granulites occur in the Central Guyana Domain (CGD) near the Uatumã-Anauá Domain (UAD) boundary, southeastern Roraima (Brazil). These rocks are oriented along NE–SW and E–W trends and dip to NW and N, respectively. Single-zircon Pb evaporation results yielded 1724 ± 14 Ma and 1889 ± 3 Ma for a syn-kinematic foliated hornblende–biotite monzogranite and a granodioritic mylonite, respectively. These results point to a new tectonic event (Itã Event) in the area in addition to the 1.94–1.93 Ga (late- to post-Transamazonian) and the 1.35–0.98 Ga (K'Mudku) thermal tectonic events. This new event may be related, at least locally, with the evolution of the Columbia Supercontinent. In addition, the Itã Fault System is younger than 1.89 Ga (granodioritic mylonite age), contrasting with the Barauana high-grade lineament and 1.94 Ga polydeformed rocks, pointing to the needs of a major revision of lithostratigraphic column currently proposed for the CGD as well as the CGD and UAD boundary.

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RESUMO

Hornblenda e biotita (meta) granitóides, milonitos, leucognaisses e granulitos, com estruturas preferencialmente NE–SW e E–W, ocorrem no Domínio Güiana Central (DGC), próximo ao limite com o Domínio Uatumã-Anauá (DUA), região central do Escudo das Güianas, sudeste de Roraima (Brasil). Os resultados fornecidos pelo método evaporação de Pb (zircão) apontam idades de 1.724 ± 14 Ma e 1.889 ± 4 Ma, respectivamente, para hornblenda-biotita monzogranito foliado (granito sincinemático) e granodiorito milonítico (Suíte Água Branca?). Desta forma, sugere-se, além dos eventos tectônicos marcados pelo intervalo de 1,94–1,93 Ga (pós-Transamazônico) e 1,35–0,98 Ga (K'Mudku), a existência de outro evento tectônico em torno de 1,72 Ga (Evento Itã), provavelmente relacionado, nesta região, à evolução do Supercontinente Columbia. Além disso, os dados sugerem que o Sistema de Falhas do Itã pode ter sido gerado ou reativado pós-1,89 Ga e os protólitos ortoderivados estudados nesta porção do DGC não se mostraram correlacionáveis àqueles de áreas vizinhas (cujas idades variam de 1,96 a 1,93 Ga), indicando a necessidade de revisão das propostas litoestratigráficas e dos limites entre os domínios conhecidos.

1. Introduction

The Central Guyana Domain (CGD, Reis and Fraga, 2000a; Reis et al., 2003) or K'Mudku Shear Belt (Santos et al., 2000, 2006a,b) has been considered as the most important structural feature in central-western Guyana Shield (Fig. 1). This major NE–SW-trending tectonic domain extends over northernmost Brazil and large areas within Guyana and Surinam. This domain has been interpreted as a collisional orogen (Hasui et al., 1984; Gibbs and Barron, 1993), although no relicts of oceanic crust have been recorded. Nevertheless, some orthogneisses (calc–alkaline crustal sources) that occur within this domain display typical subduction-related geochemical signatures. According to CPRM (1999), this calc–alkaline signature is not directly associated with mantle partial melting processes during the subduction-related, pre-col-
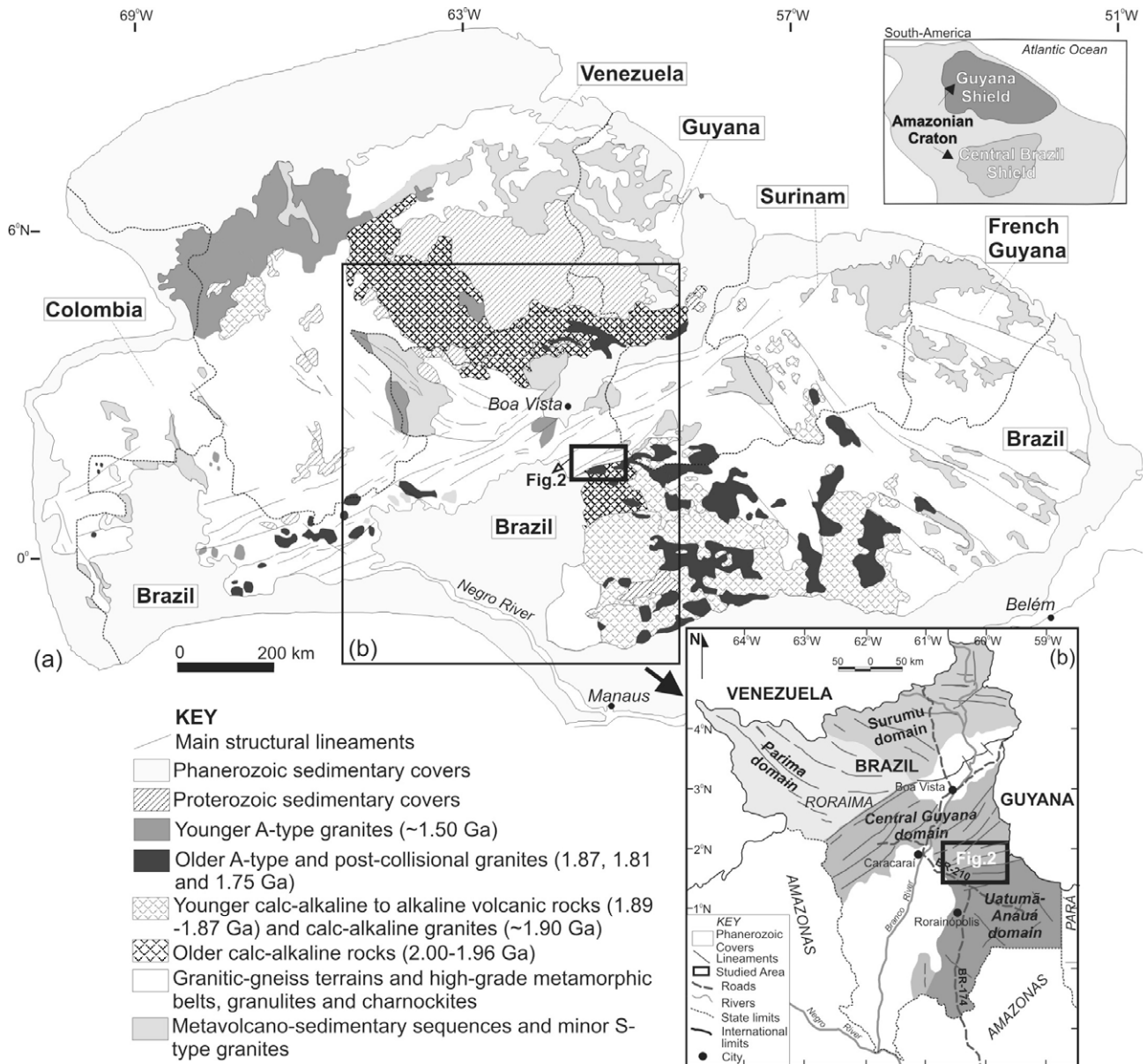
Fig. 1. Geological sketch map of the Guyana Shield (modified from Gibbs and Barron, 1993) and the location of the study area showing southeastern Roraima. The lithostructural domains of Roraima after Reis and Fraga (2000a), Reis et al. (2003) and CPRM (2006) are also shown.

lisional setting but may reflect an origin associated with an ensialic mobile belt (Cordani and Brito Neves, 1982). As such, CPRM (1999) suggested that the CGD was generated during an event in late- to post-Transamazonian times (2.26–2.01 Ga; Santos et al., 2003a) previous to an oblique movement along the limits of two colliding lithospheric plates (i.e., intracontinental orogenic belt). Further tectonic events, such as the K'Mudku (Guyana) or the Nickerie (Surinam) ones, would have erased the records of igneous and metamorphic processes that took place within the present northern and southern limits of the CGD.

This paper presents geological data for granulites, orthogneisses, mylonites and (meta) granitoid rocks and new zircon Pb geochronological data for mylonites and granitoid rocks from the CGD in southeastern Roraima (Brazil). The aim of this study is to put constraints in the southern limits of this domain as well as in chronology of the major igneous, metamorphic and tectonic events that took place in the central portion of the Guyana Shield.

2. Geology of southeastern Roraima

Two main lithostructural domains can be depicted within southern Roraima state in Brazil: the Central Guyana and Uatumã-Anauá (Fig. 1, Reis et al., 2003; CPRM, 2006). These two domains correspond, respectively, to the K'Mudku Shear Belt and the Tapajós-Parima Belt (Santos et al., 2000, 2006a,b). According to CPRM (1999), the CGD is essentially a shear belt composed of orthogneisses, metagranitoid rocks and minor granulites with a strong NE–SW and E–W foliation (Fig. 2) dipping steeply to NW. Although the age and the evolution of this shear belt still remain uncertain, Fraga and Reis (1996) reinforced that its main tectonic feature can be related to oblique thrust structures associated with a NW to SE main stress component. The most common rocks that crop out in southern CGD are orthogneisses, mylonites, metagranitoid rocks and subordinated lenses of granulites and leucogneisses (the Rio Urubu Metamorphic Suite; CPRM, 1999) associated with low- and medium- (Cauarane Group, CPRM, 1999) to high-grade
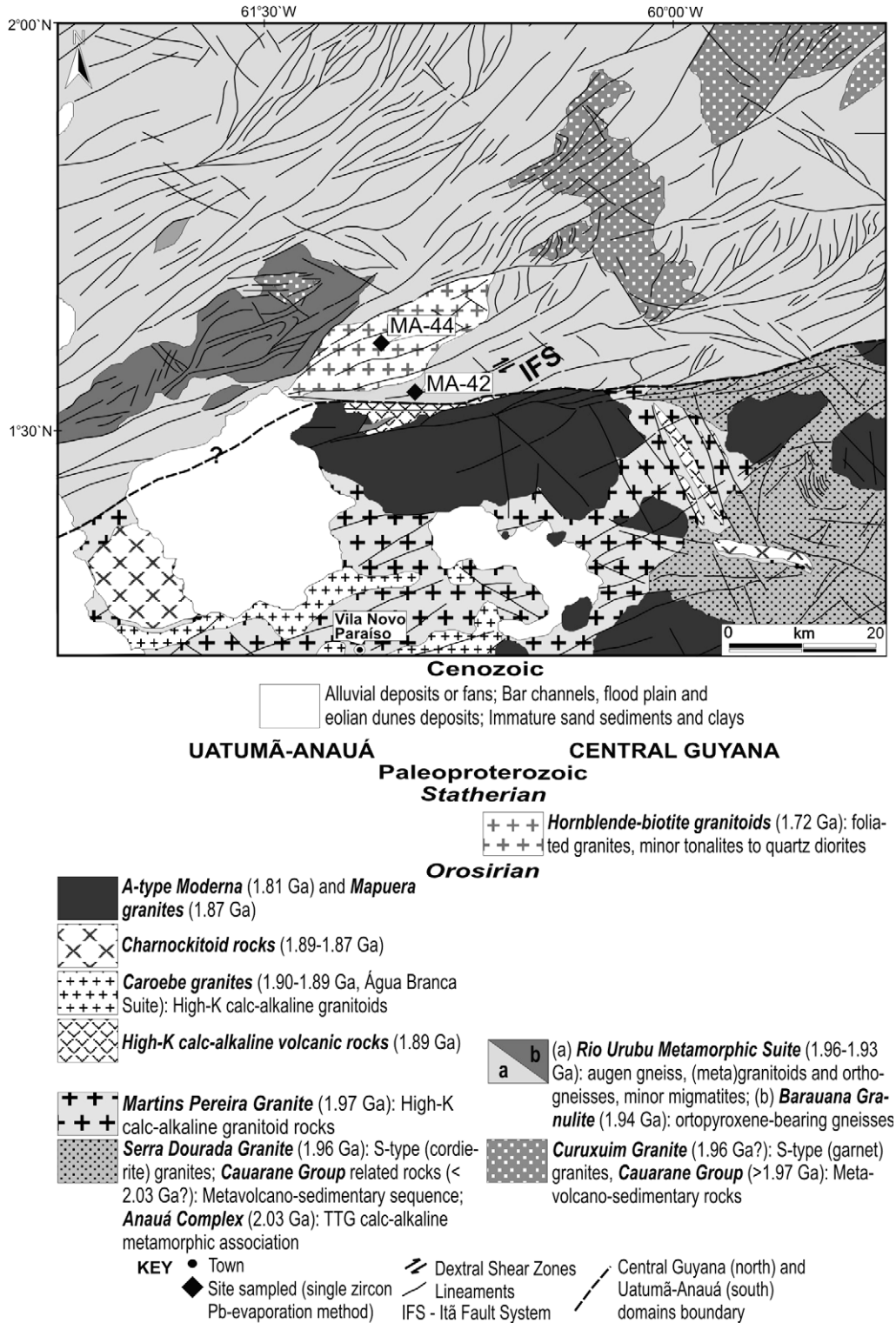
Fig. 2. Geological map of the southeasternmost Roraima state modified from CPRM (2000) and Almeida et al. (2002).

(Murupu Suite, Luzardo and Reis, 2001) metavolcanosedimentary sequences and S-type granites (Curuxuim Granite, CPRM, 1999).

The Uatumã-Anauá Domain (UAD) is characterized by E–W to NE–SW-trending lineaments and a metamorphic basement (Fig. 2) comprising TTG-like metagranitoid rocks and orthogneisses, with metamafic to metaultramafic enclaves (Anauá Complex) that have been associated with an island arc environment (Faria et al., 2002). Metavolcano-sedimentary rocks (Cauarane and

Murupu related rocks) have also been associated with the basement rocks within this area (CPRM, 2000).

The TTG and the supracrustal basement sequences were intruded by S-type (the Serra Dourada Granite) and I-type calc–alkaline (Martins Pereira) granites (Fig. 2). Altogether, they comprise the 1.96–2.03 Ga Martins Pereira-Anauá granitic terrain (Almeida et al., 2002) or the Northern Uatumã-Anauá Domain (NUAD, Almeida and Macambira, 2007) taken as the "deformed" portion of the UAD.

Younger, unmetamorphosed and undeformed sequences are represented by the Caroebe (Água Branca Suite, Fig. 2) and Igarapé Azul calc–alkaline granitoid rocks. These granitoid rocks were associated with the Iricoumé volcanic rocks (Macambira et al., 2002; Reis et al., 2000) and subordinate charnockitoid plutons (Almeida et al., 2002), and altogether comprise the "undeformed" Igarapé Azul-Água Branca granitic terrain (Almeida et al., 2002) - located on the Southern Uatumã-Anauá Domain (SUAD, Almeida and Macambira, 2007). Several A-type granite plutons (Fig. 2) are represented by the Moderna and Madeira (1.81 Ga), and Mapuera and Abonari (1.87 Ga) granites that occur within the SUAD as well as the NUAD.

3. The Central Guyana Domain in southeastern Roraima

Metagranitoid, high-grade metamorphic rocks and other metamorphic and granitoid rocks found within the CGD nearby the UAD were grouped into the Rio Urubu Metamorphic Suite (CPRM, 1999, 2000; Reis and Fraga, 2000b). The hypersthene-bearing gneisses (Barauana granulite), leucogneisses (Igarapé Khalil leucogneiss), epidote-rich biotite mylonites (Itã mylonite) and hornblende–biotite gneisses to foliated granitoid rocks of this suite were mapped along the southern limit of the CGD as part of the present work and will be described in the following sections.

3.1. The Barauana granulite

In the Guyana Shield (Fig. 1; Gibbs and Barron, 1993), high-grade metamorphic domains have been reported in the Imataca Complex (Venezuela), Kanuku (Guyana) and Bakhuis Mountains and the Coeroeni area (Surinam), as well as in eastern Amapá and central–southern Roraima (Brazil). Among these terrains, the Barauana Mountain represents a major granulite-facies domain (CPRM, 2000) in southern Roraima (Fig. 2).

The Barauana Mountain is constituted of banded, polydeformed, locally migmatized hypersthene-bearing gneisses with charnockite and enderbite composition. The migmatites show stromatic, agmatic and schollen structures and anathectic mobilizates (Fig. 3). Thin section analyses have shown that igneous textures have not been preserved in these rocks. The gneisses show granolepidoblastic textures and a mineral assemblage composed of plagioclase, alkali feldspar, hypersthene, quartz and brownish red biotite, as well as opaque minerals (mainly magnetite), apatite and zircon (Fig. 4a and b).

On a regional scale, the NE–SW foliation (N60°E/80°NW to N35°E/90°) dips steeply to NW and is generally parallel to the
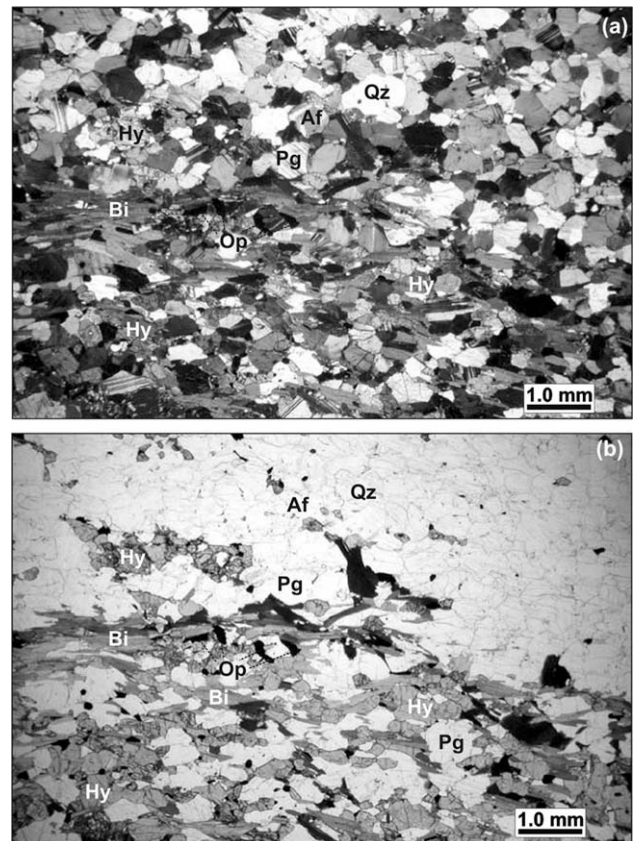

Fig. 4. Photomicrograph of charnockitic gneiss (Barauana Granulite) with bands of granoblastic charnockite (uppermost) and granolepidoblastic enderbite (lowermost). (a) Cross-polarized light and (b) plane-polarized light (1.25×). Af. Alkali feldspar; Bi. Biotite; Hy. Hypersthene; Op. Opaque minerals; Pg. Plagioclase; Qz. Quartz.

CGD regional trend. Similar trends are observed in the Kanuku Mountains, in Guyana (McConnel, 1962; Gibbs and Barron, 1993), as well as in the Bakhuis and Coeroeni Mountains, in Surinam (Bosma et al., 1983; De Roever et al., 2003).

Rims of zircon crystals in the Barauana granulite (anatexite sample) were interpreted as having a late metamorphic origin (1818 Ma, U-Pb SHRIMP), while the cores (1942 +7/−8 Ma, U-Pb SHRIMP) have been related to an anatectic event (igneous zircons) under granulitic conditions (CPRM, 2002, 2003). Syn-kinematic charnockites within the CGD (the Serra da Prata Suite, as reviewed by Fraga, 2002) yielded ages between 1934 Ma and 1943 Ma (single-zircon Pb evaporation). These ages are in general agreement with those of the Barauana granulite and all these data suggest an important granulite-facies metamorphism and a pyroxene-bearing rocks generation (anhydrous) event. Nevertheless, despite their (Barauana and Serra da Prata) similar ages, a coeval origin is yet debatable. Those ages are also younger than the Amapá (2.06–2.05 Ga; Lafon et al., 2001; Avelar et al., 2003) and Bakhuis (2.07–2.05 Ga and ~2.15 Ga inherited component; De Roever et al., 2003) ultra high-temperature (UHT) granulites, revealing an elapsed time (140–110 Ma) related to diachronous high-grade metamorphic episodes in the Guyana Shield (Fig. 1).

3.2. The Itã mylonite and the Igarapé Khalil orthogneiss

The Itã mylonite crops out near the RR-170 road, within the Itã Fault System, located on the boundary of the CGD and the UAD (Fig. 2). According to CPRM (2000), older mylonites are observed to the north, in the Lua Mountains (Vila Vilhena region), associated

Fig. 3. Outcrop of banded charnockitic gneiss (Barauana Granulite) with enderbitic enclaves as lenses (MA-207 outcrop).

with fine-grained biotite gneisses. The Itã mylonite is a medium- to fine-grained augen gneiss with granodioritic to monzogranitic compositions and abundant ovoid feldspar porphyroclasts (Fig. 5). These rocks display a N75°E to N70°E S-C foliation (dextral sense), steep NW dipping, showing mineral lineation (quartz ribbons and locally stretched feldspar) with medium-angle rake (N80°W/60°).

The mineral assemblage is mainly composed of alkali feldspar, plagioclase and biotite (and associated epidote). Epidote, quartz and feldspars are very fine-grained, recrystallized and, locally, quartz and feldspar display a granoblastic texture (Fig. 6a and b). Other accessory minerals are sphene, allanite, opaque minerals

Fig. 5. Granodioritic to monzogranitic biotite mylonite showing a conspicuous mylonitic foliation with ENE–WSW trend and NW steep dip (MA-42 outcrop).
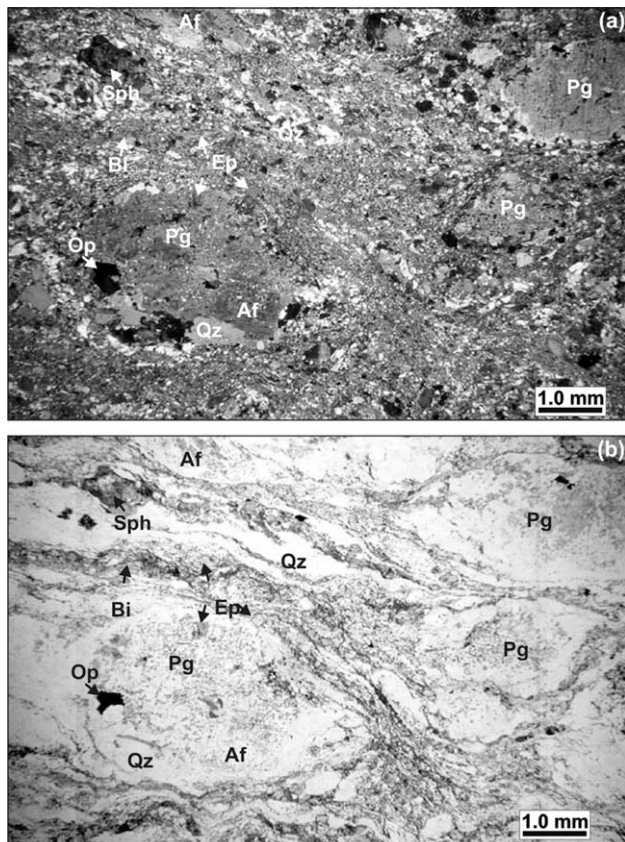

Fig. 6. Photomicrograph of porphyritic granodiorite with mylonitic texture and conspicuous foliation as well as a local fine-grained matrix and feldspar relicts. (a) Cross-polarized light and (b) plane-polarized light (1.25×). Af. Alkali feldspar; Bi. Biotite; Ep. Epidote; Op. Opaque minerals; Pg. Plagioclase; Qz. Quartz; Sph. Sphene.

(mainly magnetite), apatite and zircon. Secondary minerals are chlorite and subordinate sphene. Relict igneous textures are scarcely observed in these rocks.

The Igarapé Khalil orthogneiss crops out along the BR-174 highway being leucocratic, equigranular, fine-grained and granolepidoblastic to locally protomilonitic textures with subvertical N80°E to N50°E foliation. The mineral assemblage is composed essentially of quartz, microcline and plagioclase. Biotite and muscovite occur subordinately in this rock (~3 vol.%). Accessory minerals are represented by allanite, primary epidote, zircon, apatite and opaque minerals. Epidote, chlorite and sericite occur as secondary minerals.

3.3. The foliated amphibole–biotite granitoid rocks

Biotite–amphibole gneisses and (meta) granitoid rocks are commonly found between the Barauana Mountain and the Itã Fault System, along RR-170 road (Fig. 2). They comprise an ENE–WSW trending, lens-shaped body with slightly higher radiometric features than ohers orthogneisses in the CGD (CPRM, 1984). These rocks display a steeply NW dipping, N70°E–N75°E conspicuous foliation (Fig. 7) and a S-C fabric as a result of emplacement under amphibolite-facies conditions and a dextral transpressive regime.

These rocks are grey in color and equigranular although some display a few porphyry surrounded by a fine-grained groundmass. They have monzogranitic to syenogranitic and rarely granodioritic to quartz dioritic compositions. Biotite and amphibole (hastingsite) are the main mafic minerals and sphene, allanite, epidote, opaque minerals, apatite and zircon constitute the main accessory phases. These rocks display a mineral lineation defined by the preferred orientation of amphibole and feldspars (mainly plagioclase), as well as a foliation given by the subparallel orientation of biotite flakes.

With the exception of these structures, these granitoids seem to be strain-free or low strained rocks, suggesting deformation in the presence of a melt phase (i.e., syn-kinematic emplacement). There is no evidence for dynamic and/or static conspicuous recrystallization, and the igneous mineralogy and textures are well preserved (Fig. 8a and b). Only a few quartz grains show local grain reduction (dynamic recrystallization) and ondulatory extinction. On the other hand, CPRM (1999, 2000) have pointed out to highly deformed (solid state) rocks of similar compositions in the Barauana River and Lua Mountain, suggesting that the granite had been at least partially crystallized at the time of deformation. According to CPRM (1999), these rocks (Barauana River and Lua Mountain) can be correlated with the Kusad and Corentyne (augen) gneisses in southern Guyana.

Fig. 7. Foliated hornblende–biotite granite ("streaky gneiss") showing strong foliation and mineral lineation by magma flow (MA-44 outcrop).
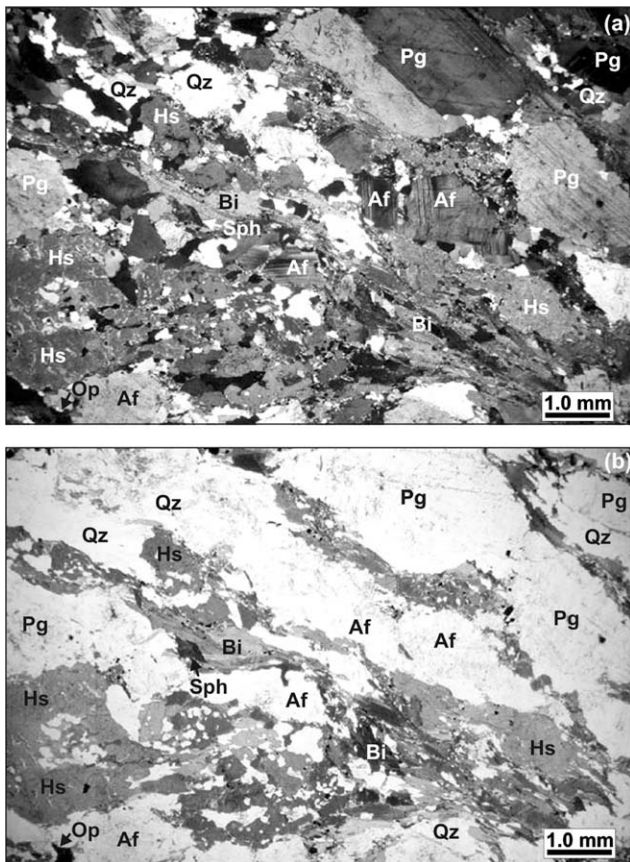
Fig. 8. Photomicrograph of foliated hornblende–biotite monzogranite with low dynamic recrystallization texture and relicts of igneous texture. (a) Cross-polarized light and (b) plane-polarized light (1.25×). Af. Alkali feldspar; Bi. Biotite; Hs. Hastingsite; Op. Opaque minerals; Pg. Plagioclase; Qz. Quartz; Sph. Sphene.

In general, the petrographic and field features described for foliated amphibole–biotite granitoid rocks suggest that they were at least partially molten by the time of their emplacement in an active tectonic zone. According to Brown and Solari (1999), sheet-like, concordant to subconcordant granites can be related with magma transport along planar conduits through an AFZ (apparent flattening zone). These authors also state that the S > L fabrics observed in these granites record the apparent flattening-to-plane strain, mainly in the case of "straight" belts.

4. Single-zircon Pb evaporation geochronology

4.1. Analytical procedures

Two to twenty kilograms of each rock sample were crushed (milled to 60–80 mesh), sieved, washed and dried out for at least 12 h. Heavy mineral fractions were obtained by water-mechanical and dense liquid concentrations, and processed under a hand magnet and a Frantz Isodynamic Separator. As much as possible, only alteration-free zircon grains were selected for analysis (zircon descriptions are presented below). In order to remove impurities, the zircon concentrates were washed with HNO_3 at 100 °C (10 min), taken to an ultrasound cube (5 min) and finally washed under twice-distilled H_2O. After drying, the concentrates were observed under the petrographic microscope and the zircon grains were selected by hand-picking.

Selected grains were then tied in re-filaments and charged into a Finnigan MAT262 mass spectrometer for isotope analysis. The $^{207}Pb/^{206}Pb$ ratios were corrected for a mass discrimination factor of 0.12% ± 0.03 a.m.u^{-1}, determined by repeated measurements of the NBS-982 Pb-standard. The $^{207}Pb/^{206}Pb$ ratio was measured during three evaporation steps at temperatures of 1450 °C, 1500 °C, and 1550 °C. The average $^{207}Pb/^{206}Pb$ ratio obtained in the highest evaporation temperature was taken for age calculations. The data were acquired using the ion-counting system of the instrument. The Pb signal was measured by peak hopping in the 206, 207, 208, 206, 207, 204 mass order along 10 mass scans, defining one block of data with 18 $^{207}Pb/^{206}Pb$ ratios. Outliers were eliminated using the Dixon's test. The $^{207}Pb/^{206}Pb$ ratio average of each step was determined on the basis of five blocks, or until the intensity beam was sufficiently strong for a reliable analysis. The ages were calculated with 2 sigma error and common Pb correction from values derived from the Stacey and Kramers (1975) model in the blocks in which the $^{204}Pb/^{206}Pb$ ratios were lower than 0.0004. The statistic levels are express by the USD or unified standard deviation (square root of MSWD – mean standard weight deviation). The data were processed using the DOS-based Zircon shareware (Scheller, 1998).

4.2. Samples, results and interpretation

Two fresh rock samples representing the Itã granodioritic mylonite (MA-42: 1°32′50″N; 60°19′48″W) and the foliated biotite–amphibole monzogranite (MA-44: 1° 36 35N; 60° 21 36W) were collected and analyzed by the single-zircon Pb evaporation method.

Six zircon crystals from sample MA-42 (porphyritic granodioritic mylonite) were analyzed, but only three (crystals #2, #4 and #5) gave results that led to age calculations. The zircon grains were non-magnetic, euhedral, pale yellow to brown, transparent to translucent crystals showing few inclusions and fractures. The crystals showed preserved faces, were 220–360 μm in length and bear a length:width ratio of around 3:1–2:1.

The analyzed crystals yielded a mean age of 1889 ± 4 Ma (Fig. 9a and Table 1) and the $^{207}Pb/^{206}Pb$ individual ages obtained at higher temperature steps were rather uniform, showing values between 1889 ± 4 Ma (grain #2) and 1892 ± 2 Ma (grain #5). Thus, the 1889 ± 4 Ma was interpreted as the crystallization age and the time of emplacement of the igneous protolith of the MA-42 mylonite. The data obtained at the lower temperature steps were eliminated from the calculation of the mean age for being less consistent, yielding younger ages (1828 ± 10 Ma to 1879 ± 8 Ma) and higher $^{204}Pb/^{206}Pb$ ratios. The Th/U ratios ranged uniformly from 0.51 to 0.58 (Table 1), similarly to the other magmatic rocks.

The mean age (1889 ± 4 Ma) is, at least, 20–75 Ma younger than that of other igneous protoliths from ortogneisses and mylonites commonly related to the Rio Urubu Metamorphic Suite in the CGD, such as the Vilhena mylonite (1950 ± 9 Ma; magmatism age and 1879 ± 4 Ma; metamorphism age) according to U-Pb zircon SHRIMP analysis (CPRM, 2002, 2003). Locally, younger mylonites were described to the south, in the Alalaú and Jauaperi rivers (CPRM, 2000), yielding 1869 ± 9 Ma by the U-Pb zircon SHRIMP method (Santos et al., 2002; CPRM, 2003). On the other hand, igneous ages of around 1.89–1.90 Ga were only observed nearby the Igarapé Dias (CPRM, 2003) and Caroebe granitoid rocks (Água Branca Suite), both in the southeast of Roraima. Thus, despite the difficulties concerning the protolith identification, the 1.89 Ga age in association with the mineral assemblage (e.g. biotite, epidote and calcic zoned plagioclase), as well as granodioritic to monzogranitic compositions, suggest that the igneous protolith of the Itã mylonite is a granitoid rock related with the Caroebe (Água Branca Suite) magmatism.

Twenty zircon crystals collected from sample MA-44 (foliated hornblende-bearing granite) were analysed, but only five crystals (crystals #6, #8, #12, #14 and #18) gave results that led to age
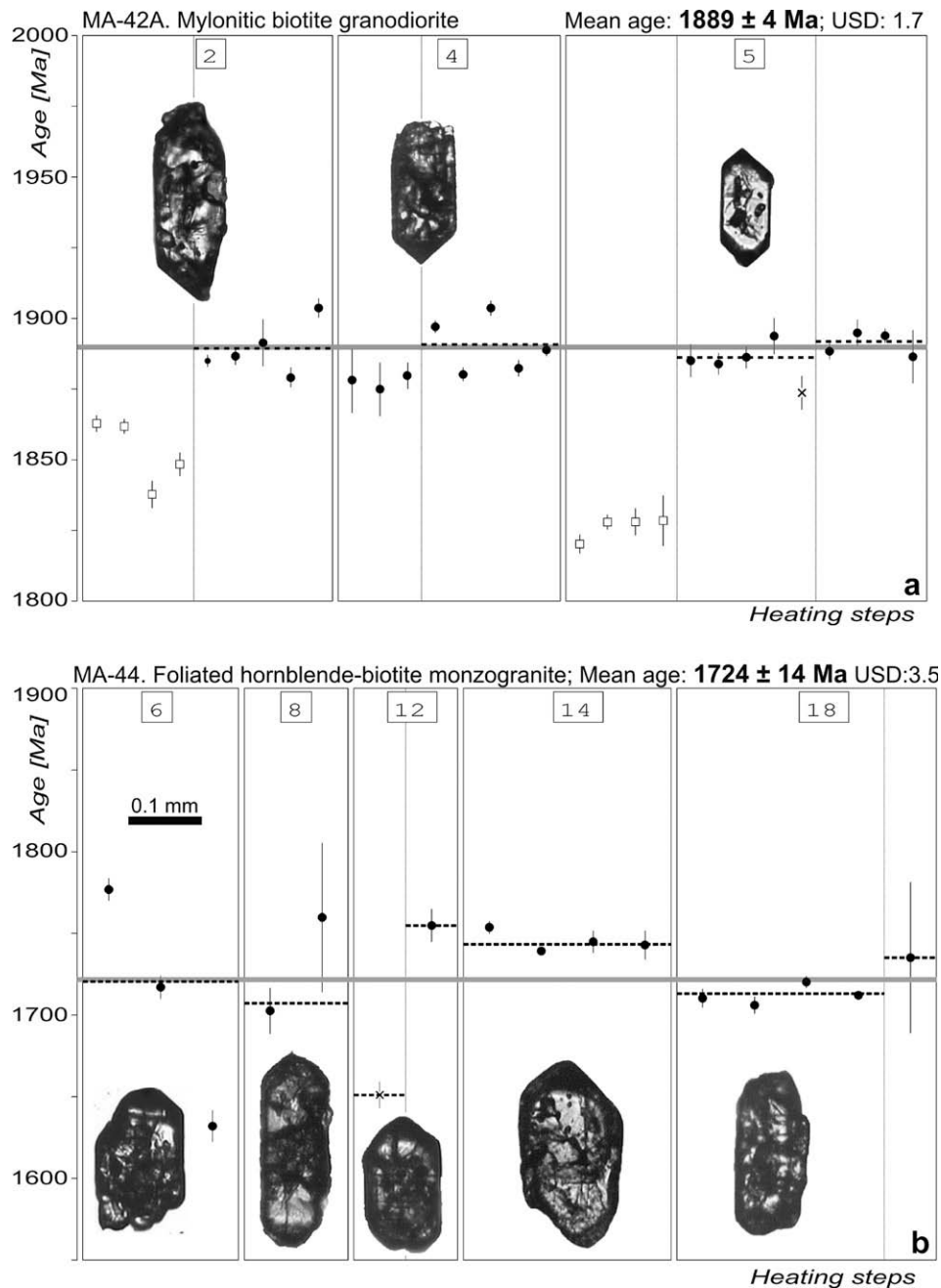
Fig. 9. Single zircon Pb evaporation age diagram of (a) mylonitic biotite granodiorite and (b) foliated hornblende–biotite monzogranite. Filled circle – accepted blocks for age calculation. Square – blocks not used due to their higher or lower values of the $^{207}Pb/^{206}Pb$ ratio in relation to the mean. X – rejected blocks due to $^{204}Pb/^{206}Pb > 0.0004$. Crystal numbers are indicated (see Table 1). The scale bar is the same for all diagrams.

calculations (Fig. 9b and Table 1). The zircon grains were euhedral crystals with 180–370 μm in length and length:width ratio of around 2:1. They showed slightly rounded vertices and slightly irregular faces. The grains were pale yellow, transparent to translucent, with several inclusions and fractures, being also weakly magnetic.

The analyzed crystals yielded a mean age of 1724 ± 14 Ma (Fig. 9b), but the $^{207}Pb/^{206}Pb$ individual ages obtained under the 1450–1500 °C evaporation steps were not homogeneous, giving high errors, and values between 1707 ± 16 Ma (grain #8) and 1755 ± 10 Ma (grain #12). Thus, this mean age is interpreted as a minimum crystallization age of the analyzed crystals. Grain #3 gave the oldest age (1827 ± 23 Ma) and has been taken as an inherited crystal. This age is similar to those obtained for the Moderna

Granite (Santos et al., 1997). The Th/U ratios ranged from 0.36 to 0.50 (Table 1), resembling those found in magmatic systems.

The mean minimum crystallization age of 1.72 Ga is at least 200 Ma younger than those of the other orthogneisses and metagranitoid rocks correlated to the Rio Urubu Metamorphic Suite, in the CGD (Gaudette et al., 1996; Fraga, 2002). These foliated granitoid rocks yielded Nd model age (T_{DM}) of 2.07 Ga and $\varepsilon_{Nd(i)} = -0.91$ (T_{cryst} 1724 Ma), suggesting probably juvenile (depleted) crustal protoliths with late-Transamazonian ages and no appreciable mantle contribution.

Ar–Ar ages on a muscovite crystal from sheared granitoid rocks within the UAD, close to the boundary with GCD, yielded values between 1656 ± 4 Ma and 1710 ± 4 Ma (CPRM, 2002), recording an important cooling event (near 350 °C Ar–Ar blocking temperature;

Table 1
Single-zircon Pb evaporation isotopic data for mylonitic biotite granodiorite (MA-042) and foliated hornblende–biotite monzogranite (MA-044) samples

Sample/zircon number	Temperature (°C)	Ratios	$^{204}Pb/^{206}Pb$	2σ	$^{208}Pb/^{206}Pb$	2σ	$^{207}Pb/^{206}Pb$	2σ	$(^{207}Pb/^{206}Pb)_{(c)}$	2σ	Age	2σ	Th/U
Mylonitic biotite granodiorite													
MA42/01	*1450	0/8	*0.000116*	*26*	*0.18932*	*213*	*0.11578*	*63*	*0.11578*	*72*	*1868*	*11*	*0.54*
MA42/02	*1450	0/28	*0.000112*	*23*	*0.17927*	*74*	*0.11535*	*25*	*0.11354*	*64*	*1857*	*10*	*0.51*
	1500	36/36	0.000014	2	0.19437	71	0.11565	47	0.11559	50	1888	8	0.55
MA42/03	#1450	0/32	*0.000651*	*41*	*0.20128*	*60*	*0.12094*	*23*	*0.11176*	*63*	*1828*	*10*	*0.58*
MA42/04	1450	18/18	0.000154	12	0.19439	168	0.11663	38	0.11490	50	1879	8	0.55
	1500	32/32	0.000016	9	0.20432	107	0.11578	49	0.11567	54	1891	8	0.58
MA42/05	*1450	0/20	*0.000359*	*12*	*0.14187*	*189*	*0.11625*	*20*	*0.11159*	*26*	*1826*	*4*	*0.44*
	1500	38/38	0.000063	9	0.17983	160	0.11622	28	0.11528	33	1885	5	0.51
	1550	26/26	0.000077	5	0.17843	63	0.11684	22	0.11575	22	1892	3	0.51
MA42/06	*1450	0/36	*0.000157*	*26*	*0.18369*	*195*	*0.11334*	*39*	*0.11171*	*71*	*1828*	*12*	*0.57*
	*1500	0/8	*0.000073*	*16*	*0.19334*	*296*	*0.11483*	*41*	*0.11385*	*47*	*1862*	*7*	*0.60*
		150 (282)							Mean age		1890	4	USD 1.7
Foliated hornblende–biotite monzogranite													
MA44/03	*1450	0/16	*0.000494*	*89*	*0.07691*	*73*	*0.10150*	*194*	*0.09526*	*110*	*1533*	*22*	*0.22*
	*1500	0/16	*0.000086*	*2*	*0.17460*	*132*	*0.11172*	*139*	*0.11167*	*141*	*1827*	*23*	*0.50*
MA44/05	*1450	0/8	*0.000000*	*0*	*0.15711*	*169*	*0.10363*	*53*	*0.10363*	*53*	*1690*	*9*	*0.45*
MA44/06	1450	22/22	0.000079	26	0.16616	3523	0.10363	370	0.10534	222	1721	77	0.48
MA44/07	#1450	0/8	*0.000521*	*44*	*0.15396*	*118*	*0.11148*	*41*	*0.10437*	*73*	*1703*	*13*	*0.44*
MA44/08	1500	14/14	0.000363	106	0.11318	224	0.10925	65	0.10459	179	1707	32	0.33
MA44/11	*1450	0/28	*0.000375*	*3*	*0.13889*	*105*	*0.10778*	*30*	*0.10258*	*45*	*1672*	*8*	*0.40*
MA44/12	#1450	0/8	*0.001250*	*58*	*0.19704*	*106*	*0.11860*	*35*	*0.10153*	*88*	*1652*	*16*	*0.57*
	1500	8/8	0.000136	34	0.17190	192	0.10918	108	0.10733	118	1755	20	0.50
MA44/14	1450	26/26	0.000391	6	0.16686	70	0.11208	16	0.10666	26	1743	9	0.48
MA44/16	*1450	0/14	*0.000314*	*6*	*0.15654*	*249*	*0.10736*	*16*	*0.10736*	*16*	*1684*	*6*	*0.45*
MA44/17	*1450	0/28	*0.000305*	*2*	*0.13550*	*37*	*0.10395*	*36*	*0.10395*	*28*	*1617*	*5*	*0.39*
MA44/18	1450	26/26	0.000277	21	0.13612	113	0.10872	37	0.10492	29	1713	5	0.39
	1500	8/8	0.0000092	12	0.12460	670	0.10618	268	0.10618	268	1735	46	0.36
		104 (230)							Mean age		1724	14	USD 3.5

Notes: The total blocks analyzed are shown in parentheses in the ratios column, but only the ratios out of parentheses were used for age calculation. Values in italics were not included in the age calculation of the grain (# – step not used due to scatter greater than two standard deviations from the average age; * – step manually discarded due to higher or lower values of the $^{207}Pb/^{206}Pb$ ratio in relation to the mean. (C) ratios corrected for initial common Pb. Th/U ratios were calculated as such: Th = [$(^{208}Pb/^{206}Pb)$/$(\lambda Th * T) - 1$] + $(^{208}Pb/^{206}Pb)$; U = [$(^{208}Pb/^{206}Pb)$/$(\lambda U * T) - 1$] + $(^{208}Pb/^{206}Pb)$; $\lambda Th = 4.94750 * 10^{-12}$; $\lambda U = 1.55125 * 10^{-11}$ (in Klötzli, 1999).

Hodges, 1991) in southeastern Roraima. These Ar–Ar ages are in good agreement with the foliated amphibole–biotite granite age (1724 ± 14 Ma).

5. Tectonic setting of the Central Guyana Domain in southeastern Roraima: a discussion on the collisional model

The CGD has been taken as a major collisional orogen by many authors in the past years (e.g. Cordani and Brito Neves, 1982; Hasui et al., 1984; Gibbs and Barron, 1993; Fraga and Reis, 1996; Costa and Hasui, 1997; CPRM, 1999; Santos et al., 2000, 2006a,b). In general, granulite terranes in collisional orogens follow a clockwise PT path (e.g. Ellis, 1987; Brown and Dallmeyer, 1996; Brown, 2001) and their exposure has been attributed to isostatic rebound as a result of crustal thickening during one or more tectonic events (Ellis, 1987).

Nevertheless, many granulite terranes seem to have been too hot to have formed during continental collision and may represent thickened hot orogens associated with underplating processes within other tectonic settings (Collins, 2002a). For instance, granite generation in the Paleozoic Lachlan Fold Belt and Circum-Pacific regions was assisted by heat advected from the mantle during protracted regional extension under low- to medium-P granulite-facies (Collins, 2002b). These recent studies have pointed out that some granulites are unlikely to be related with collisional tectonics. Furthermore, collisional orogens develop when an ocean closes between continental blocks. However, many orogenic systems have not experienced collision, being called accretionary (e.g. Coney, 1992), with the Lachlan orogen as an excellent example.

Even in classic collisional orogens, such as the European Alps and Himalayas, coeval granites and granulites are rare. On the contrary, broad zones of anomalously high heat flow occur in extensional and accretionary orogens, leading to widespread silicic magmatism, as in the Basin and Range Province, the Taupo volcanic zone, the Circum-Pacific orogens and some Precambrian terranes (e.g. Central Australia, Collins, 2002a). These orogens are characterized by voluminous granitic batholiths associated with repeated extensive–compressive events and are underlain by granulites. The latter are only scarcely exposed (e.g. Ducea, 2001) because crustal thickening rarely occurs. Even so, granulite xenoliths found in modern basalts in those orogens point out to the existence of a granulite basement (e.g. Chen et al., 1998). All these data suggest that granulites would have been more commonly associated with accretionary orogens than collisional ones. Nevertheless other authors have argued that the association of granulite terranes with repeated tectonic events has only local application, as in the case of the Lachlan orogen, since it does not apply to other UHT and HP granulite terrains undoubtedly related to collisional tectonics as in the case of the Variscan, Brasília and Grenville orogens (Brown, 2003).

6. Crustal amalgamation processes in global-scale: the supercontinent theory and its application in the Central Guyana Domain

The Amazonian Craton evolution has been closely associated with those of the Laurentia and Baltic cratons in the northern hemisphere (e.g., Rogers, 1996). Lateral magmatic arc accretion seems to have taken place in those cratons in Statherian times (Paleoproterozoic: 1.80–1.60 Ga) as well as taphrogenic events within the pre-Statherian domains (e.g., Atlantica) onto the Columbia supercontinent (Rogers and Santosh, 2002; Brito Neves and Almeida, 2003). These Statherian events are well-recorded in the Yavapai (1.75–1.68 Ga; e.g., Duebendorfer et al., 2001) and Cheyenne (1.78–1.75 Ga; e.g., Sims and Stein, 2003) orogens within Laurentia as well as in the Rio Negro (1.82–1.52 Ga) and

Rondonian-Juruena (1.82–1.54 Ga) provinces within the Amazonian Craton (Santos et al., 2000, 2006a).

In the central portion of Guyana Shield in southern Roraima (Fig. 1), granitic magmatism is unknown at Statherian times but could be represented by the syn-kinematic biotite–amphibole granite emplaced around 1.72 Ga. In the western region of the Guyana Shield (Rio Negro Province), Statherian rocks are represented by arc-related meta-quartz diorites with ~1.70 Ga (Tassinari et al., 1996, zircon U-Pb ID TIMS), ~1.75 Ga A-type granites (Almeida et al., 2006, single-zircon Pb evaporation) and ~1.79 Ga basement rocks (CPRM, 2003, zircon U-Pb SHRIMP). In the Central Brazil Shield, the Rondonian-Juruena (1.82–1.54 Ga) province has also tonalities, granites and coeval volcanic rocks with 1.79–1.75 Ga, all formed in an arc-related tectonic setting (Alto Jauru orogen, Pinho et al., 1997; Geraldes et al., 2001).

This apparent scarcity of Statherian magmatism in Roraima contrasts with that of Laurentia and Baltic cratons. For instance, in Laurentia zircon geochronology studies (U-Pb SHRIMP and ID TIMS) gave ages of 1721 ± 15 Ma for the Boulder Creek Batholith (Premo and Fanning, 2000) as well as 1737 ± 4.3 Ma, 1719 ± 1.2 Ma and 1721 ± 2.4 Ma for the Big Wash, Diana and Chloride granites, respectively (Duebendorfer et al., 2001). Similarly, ~1.70 Ga syntectonic plutons (Wet Mountains; Siddoway et al., 2000) and muscovite and biotite Ar–Ar plateau ages (~1.74–1.70 Ga) obtained for samples from the western Trans-Hudson Orogeny (Heizler et al., 2000) closely resemble those in southeastern Roraima obtained for foliated hornblende–biotite granites (1.72 Ga, this paper) and muscovite in shear zones (1.71–1.66 Ga, CPRM, 2002). These data suggest the involvement of the southeastern Roraima lithosphere in the Columbia supercontinent evolution at least on a local scale.

Accretionary and collisional orogens have also affected the Amazonian, Laurentia and Baltica cratons in late Mesoproterozoic times. Geochronological Rb–Sr and K–Ar data (Pinson et al., 1962; Barron, 1966; Priem et al., 1971; Amaral, 1974; Lima et al., 1974; Basei and Teixeira, 1975; Tassinari, 1996) showed that the K'Mudku Event (Barron, 1966) took place within the 1.35–0.98 Ga range as confirmed by recent Rb–Sr and Ar–Ar geochronology (Fraga, 2002; Santos et al., 2003b). As such, the K'Mudku Event in Roraima can be interpreted as a far-field, intracratonic effect of the continental collision (Grenvilian-Sunsas belt) within the southwestern and northwestern Amazonian Craton. This event can also be related with the Rodinia supercontinent amalgamation, according to Brito Neves (1999).

In summary, the data presented in this section strongly suggest that the central portion of the Guyana Shield (northern Amazonian Craton) in southeastern Roraima has played a role in repeated episodes of supercontinental amalgamation as follows: the Atlantica (1.94–1.93 Ga, late-collisional stage?), Columbia (1.72–1.66 Ga, accretionary stage?) and Rodinia (1.35–0.98 Ga, collisional stage) supercontinents. According to Fraga (2002), the older (~1.94 Ga) and younger (~1.20 Ga) tectonic events are related to higher (>450 °C) and lower (<300 °C) temperatures, respectively. CPRM (1999) suggest also an intermediate tectonic event in age (not dated), named as Macuxi event, this last one probably related to the 1.72–1.66 Ga interval age (this paper).

7. Discussion and conclusions

The gneissic and granitic rocks of the Central Guyana Domain in the studied area have been distinctly affected by varied tectonometamorphic processes. These rocks comprise at least three metaigneous types: (1) high-grade polydeformed granulitic rocks, with local retrograde low- to medium-grade metamorphism (Barauana granulite), (2) leucogneisses and mylonitic rocks affected by a single deformation phase under medium- to high-grade metamorphism (the Itã Mylonite), and (3) low-grade metamorphic metagranitoids rocks and hornblende–biotite granites with flow foliation and relict igneous fabric (foliated hornblende–biotite granite).

These rocks were originally taken as part of the Rio Urubu Metamorphic Suite (CPRM, 1999) but the ages obtained for the Itã mylonite (1.89 Ga) and the foliated hornblende–biotite granites (1.72 Ga) are respectively 40–70 Ma and 200–240 Ma younger than those obtained for the magmatic protoliths found elsewhere within the Rio Urubu Metamorphic Suite (1.93–1.96 Ga). In addition, these rocks show post 1.89 Ga deformation episodes. The new geochronological data presented in this paper indicate that the proposed lithostratigraphy for the CGD has to be reviewed, including its boundary with the Uatumã-Anauá Domain.

The 1.72 Ga, syn-kinematic granitic magmatism (foliated hornblende–biotite granitoid rocks) in the Central Guyana Domain as well as the Ar–Ar ages (~1.70 Ga, CPRM, 2002) suggest that a tectonic event intermediate in age to the late- to post-Transamazonian (~1.94 Ga, Fraga, 2002) and K'Mudku (~1.20 Ga, Fraga, 2002) events took place in the studied area. On a preliminary basis, we suggest this to be named as the Itã Event, although it may be related with the Macuxi event as seen elsewhere (CPRM, 1999).

The K'Mudku Event has been detected in the area by means of several Rb–Sr (e.g. Amaral, 1974; Santos et al., 2000; Fraga, 2002), K–Ar (e.g., Amaral, 1974) and a few Ar–Ar (Santos et al., 2003b) ages. These ages are normally related with low to medium temperatures shear zones, locally associated with pseudotachyllites (CPRM, 1999).

The 1.89 Ga Itã granodioritic mylonite is similar in composition with the Caroebe granitoids (Água Branca Suite), located in the Uatumã-Anauá Domain. The mylonite is probably the result of greenschist to epidote–amphibolite metamorphism of the Caroebe granite within wide shear zones. Thus, the E–W Itã Fault System post-dates these 1.89 Ga granitoids (K'Mudku or Itã related events?), and the location of the Central Guyana Domain boundaries also need to be reviewed. This boundary probably would be displaced to the north and placed along the older NE–SW Barauana lineament trends, but detailed mapping and new geophysical airborne data are still needed to test for this hypothesis.

In conclusion, the data presented in this paper indicate that the structural pattern observed in the Central Guyana Domain in southeastern Roraima can be related with a main 1.94–1.93 Ga tectonic event affected by decoupled younger events (reactivation processes), namely the Itã (1.72–1.66 Ga) and the K'Mudku (1.35–0.98 Ga) events. This implies that the studied area has been subjected to major, recurrent tectonics in the Central Guyana Domain, possibly related with continental-scale processes in the central portion of the Guyana Shield.

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