Archean crustal remnants in the easternmost part of the Guiana Shield:

Pb-Pb and Sm-Nd geochronological evidence for Mesoarchean versus Neoarchean signatures

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Reliques crustales archéennes dans la partie orientale du Bouclier guyanais. Mise en évidence de signatures mésoarchéenne et néoarchéenne par la géochronologie Pb-Pb et Sm-Nd

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Key words: Dating, Pb-Pb Zircon, Sm-Nd, Whole rock, Archean, Amapá, Brazil, French Guiana, Guiana Shield.

Abstract

Single-zircon Pb-evaporation and whole-rock Sm-Nd dating have been carried out on meta-igneous and metasedimentary rocks from the easternmost part of the Guiana Shield. In central Amapá, zircons from felsic granulite and from a tonalitic orthogneiss have respectively indicated a minimum $^{207}Pb/^{206}Pb$ age of 2.58 Ga and a $^{207}Pb/^{206}Pb$ age of 2849 ± 6 Ma for the crystallization of the protoliths; Nd TDM model ages for the same units indicate a Mesoarchean episode of crust-mantle differentiation in the range of 2.92–3.29 Ga. At the border between southeastern French Guiana and Amapá State of Brazil, detrital zircons from a quartzite from the Camopi region have provided $^{207}Pb/^{206}Pb$ ages between 2.77 Ga and 3.19 Ga for the source rocks; zircons from a garnet-bearing paragneiss located in the same area yielded $^{207}Pb/^{206}Pb$ ages up to 2.85 Ga for an inherited lead component and a Nd T_{DM} model age of 2.45 Ga, interpreted as an average age of mixed source. Metagranitoid, paragneiss and migmatite from the Camopi and Oyapock regions provided Nd T_{DM} model ages between 2.24 and 2.58 Ga, revealing that these rocks originated from a juvenile mantle-derived source as well as from mixed sources, including an Archean crustal component. The geochronological results provide further evidence of the existence of Archean relics in the southeastern Guiana Shield and suggest that a greater volume of Archean continental crust was involved in the Paleoproterozoic crust than has been supposed up to now. The Archean remnants occur as preserved Meso- to Neoarchean nuclei in central Amapá and as recycled Mesoarchean crustal material in Paleoproterozoic rocks in southeastern French Guiana.

Resumo

Novos dados geocronológicos foram obtidos pelo método Sm-Nd em rocha total e de evaporação de Pb em zircões de rochas meta-sedimentares e meta-igneas da porção leste do Escudo das Guianas. Os cristais de zircão extraídos de granulitos e de um ortognaisse tonalítico da região central do Amapá indicaram, respectivamente, idades mínima $^{207}Pb/^{206}Pb$ de até 2,58 Ga para a formação dos precursores dos granulitos e uma idade de 2849 ± 6 Ma para a cristalização do protólito do ortognaisse. As idades modelo $TNd_{(DM)}$ dessas mesmas rochas registraram um episódio mesoarqueano de acreção crustal no intervalo entre 2,92 – 3,29 Ga. Os cristais de zircão detríticos de um quartzito da região de Camopi, na fronteira entre Guiana Francesa e o Amapá forneceram idades $^{207}Pb/^{206}Pb$ em um intervalo de 2,77 a 3,19 Ga para as rochas fontes. Os cristais de zircão de um paragnaisse da mesma área apresentaram um componente de Pb herdado de até 2,85 Ga e uma idade modelo $T_{(DM)}$ de 2,45 Ga resultando de uma mistura de fontes. Outros metagranitóides,

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paragnaisses e migmatitos da mesma área forneceram idades modelo $T_{(DM)}$ entre 2,24 e 2,58 Ga, o que indica que essas rochas foram derivadas de fontes mantélicas juveneis paleoproterozóicas assim como de fontes mistas, incluindo um componente crustal arqueano. Os resultados geocronológicos confirmam a presença de relíquias arqueanas envolvidas no sudeste do Escudo das Guianas e indicam que o volume da crosta arqueana remobilizada no Paleoproterozóico é maior do suposto até então. Essas relíquias ocorrem na forma de núcleos meso- a neoarqueanos na região central do Amapá e como fonte crustal mesoarqueana de rochas paleoproterozóicas no sudeste da Guiana Francesa.

Introduction

The existence of an Archean basement in the easternmost part of the Guiana Shield has been widely discussed (Gaudette *et al*., 1976; Priem *et al*., 1978; Bosma *et al*., 1983; Gibbs and Barron, 1993; Lima *et al.*, 1991; Lafon *et al*., 1998; Vanderhaeghe *et al*., 1998; Tassinari and Macambira, 1999; Tassinari *et al*., 2000; Santos *et al*., 2000; Ricci *et al*., 2001; Lafon and Avelar, 2002). Only in the northern part of the Guiana Shield are U-Pb, Rb-Sr ad Sm-Nd results on Paleoproterozoic metamorphic and igneous rocks from the Imataca Complex admitted as recording a complex Archean history (Montgomery and Hurley, 1978; Montgomery, 1979; Teixeira *et al.*, 1999; Tassinari *et al.,* 2001). A Rb-Sr age of about 2.76 Ga has been proposed for the protolith of high-grade metamorphic rocks from the Central Guyana belt in Suriname (Gaudette *et al*., 1976), but further Rb-Sr, U-Pb and Pb-Pb results do not indicate any involvement of Archean crust in the Paleoproterozoic granulites (Priem *et al*., 1978; Bosma *et al*., 1983; Delor *et al*., 2001a). On the other hand, Rb-Sr ages of 2.45 Ga and 2.9 Ga obtained respectively on charno-enderbite and tonalitic gneiss from central Amapá point to the existence of Archean relics in the easternmost part of the Guiana Shield (João and Marinho, 1982a; Montalvão and Tassinari, 1984). Recent Sm/Nd model ages on the tonalitic gneiss reinforce the assumption that an Archean crust was reworked by the Transamazonian orogeny in central Amapá (Sato and Tassinari, 1997). The Pb-evaporation method on zircon (Kober, 1986, 1987), even though involving uncertainties concerning the crystallization ages of rocks that have undergone a complex geological history, can be a powerful tool, together with Nd model ages, for identifying the presence of an old inherited Pb component in younger zircons or for determining a magmatic age in metamorphic rocks (Jaeckel *et al*., 1997; Kouamelan *et al*., 1997; Bartlett *et al*., 1998). The aim of this paper is to provide new geochronological evidence of the existence of Archean relics in meta-igneous and metasedimentary rocks from the southeastern part of the Guiana Shield, and to estimate its nature and geographical extension with special reference to the Archean-Proterozoic boundaries.

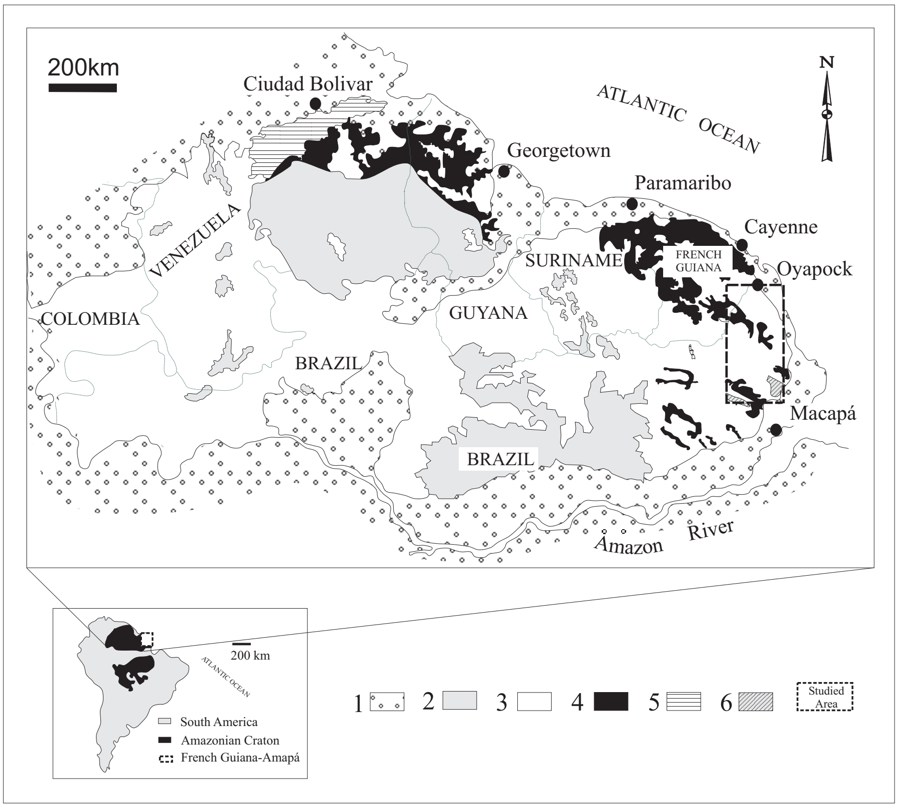

Fig. 1.- Geological map of the Guiana Shield (modified from Gibbs and Barron, 1993). 1. Post-Precambrian sedimentary covers, 2. Proterozoic sedimentary covers and acid volcanics (Roraima group and Uatumã group), 3. Paleoproterozoic granitoids, 4. Greenstone belts, 5. Archean gneisses, metasediments and granitoids (Imataca complex), 6. Archean gneisses partly granulitic and orthogneisses.

Fig. 1.- Carte géologique du Bouclier guyanais (modifiée d'après Gibbs & Barron 1993). 1. Couvertures sédimentaires phanérozoïques, 2. Couvertures sédimentaires et formations volcaniques acides protérozoïques (groupe Roraima et groupe Uatumã), 3. Granitoïdes paléoprotérozoïques, 4. Ceintures de roches vertes, 5. Gneiss, granitoïdes et métasédiments archéens (complexe de l'Imataca), 6. Gneiss en partie granulitique et orthogneiss archéens.

Geological setting

The easternmost part of the Guiana Shield (EGS) coincides roughly with Amapá State in Brazil and French Guiana (Fig. 1). Various tectonic models have been proposed to reconstruct the geodynamic evolution of this sector of the Guiana Shield and its relationships with other domains of the Amazonian craton. Cordani *et al*. (1979) and Cordani and

Neves (1982) include the EGS within the Maroni-Itacaiúnas Province (MIP; Fig. 2) -a Paleoproterozoic belt accreted to an Archean block (Central Amazonian Province) during a collisional orogeny corresponding to a major period of crustal growth at *ca.* 2.22–1.95 Ga. This model has been refined by the input of new geochronological results in an attempt to better evaluate the proportion of newly accreted crust and reworked domains in the MIP (Teixeira *et al.*, 1989; Tassinari, 1996; Sato and Tassinari, 1997; Tassinari and Macambira, 1999). A two-stage model of the Transamazonian evolution of the MIP was proposed for northern French Guiana by Vanderhaeghe *et al*. (1998) and refined by Delor *et al.* (2000, 2001b, 2003) for the whole of French Guiana. Following the formation of an oceanic crust, documented by the SIMS U-Pb zircon age of 2208 ± 12 Ma (unpublished) obtained on the Fe-gabbro of "Pointe Buzaret" (Delor *et al.*, 2001b), a first stage of "crustal growth by magmatic accretion", dominant tonalitic magmatism and regionally associated greenstone belts are interpreted in a scenario of "island arc plutono-volcanism" from 2.20 to 2.13 Ga (Eo- to Meso-Transamazonian). At *ca.* 2.10 Ga, granitic magmatism occurred in response to the closure of island-arc basins and an evolution from southward-directed subduction to sinistral wrenching. Th opening of the detrital basin containing the late Upper Sedimentary Unit (USU) also occurred during this stage in areas where crustal stretching was maximum (pull-apart basins). The final transcurrent movements, contemporaneous with 2.08-2.06 Ga emplacement of leucogranite in French Guiana, were amplified farther west in Suriname and culminated with the metamorphic climax of the Bakhuis Ultra High Temperature (UHT) granulite (Roever, 1975; Roever *et al*., 2003) dated at *ca.* 2.07-2.06 Ga by the Pb-Pb method on zircon. A similar UHT event at *ca*. 2.06–2.05 Ga is also suspected in central and northern Amapá from Pb-Pb zircon dating of charnockitic plutons close to Tartarugal Grande and Calcoene cities, respectively (Avelar *et al.*, 2001; Lafon *et al*., 2001).

Such geological markers are interpreted as the result of mantle-driven processes active at least from 2.1 Ga, and still debatable for earlier stages of the juvenile crust formation (Delor *et al*., 1998, 2000).

The main geological units of the EGS (Fig. 3) can be divided into high-grade metamorphic complexes, greenstone sequences and other supracrustal units, and granitoids and related magmatic rocks (Teixeira *et al.*, 1989; Tassinari *et al.*, 2000); granulitic rocks occur essentially in central Amapá. The main occurrence is the Tartarugal Grande metamorphic suite, which consists mainly of felsic gneiss and granulite with minor occurrences of mafic-sedimentary rock. The mafic-sedimentary units have been considered as the high-grade equivalent of the Paleoproterozoic greenstone sequences (Vila Nova group) in Amapá (João and Marinho, 1982a). Nevertheless, previous Rb-Sr dating of charno-

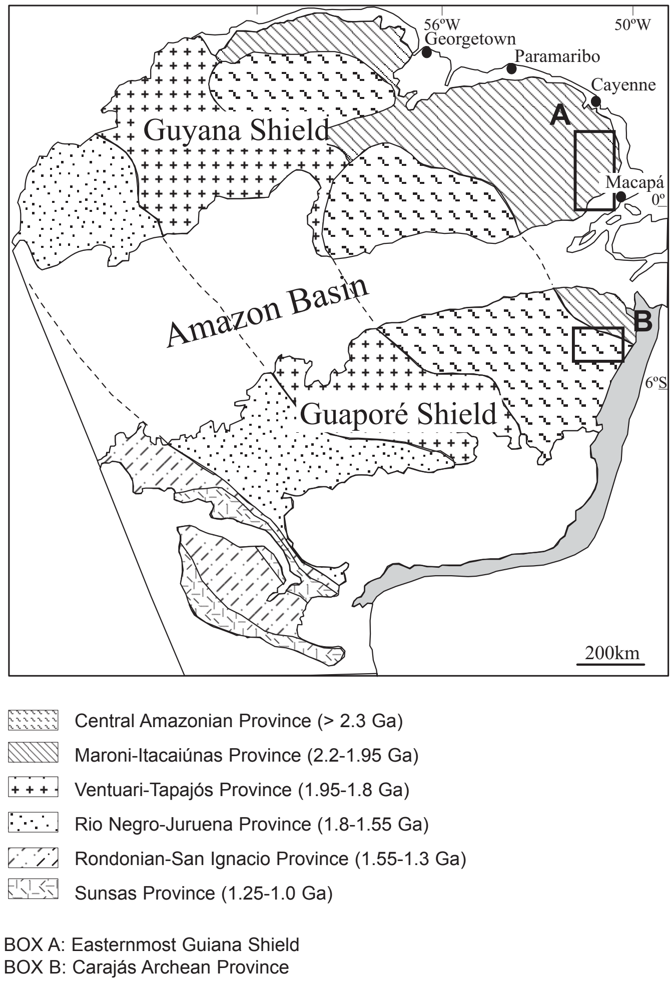

Fig. 2.- Geochronological provinces of the Amazonian craton (from Tassinari and Macambira, 1999).

Fig. 2.- Provinces géochronologiques du craton amazonien (selon Tassinari et Macambira, 1999).

enderbite in the Tartarugal Grande region indicates an age of 2450 ± 74 Ma (João and Marinho, 1982a). In the central-southern part of Amapá, tonalitic orthogneiss in the south of the Serra do Navio greenstones also yield Archean Rb-Sr and Sm-Nd ages (Montalvão and Tassinari, 1984; Sato and Tassinari, 1997). The greenstone sequences (Vila Nova Group in Amapá, and Paramaca Group in French Guiana) occur as roughly WNW–ESE-oriented belts and are generally metamorphosed in the greenschist facies. Vanderhaeghe *et al.* (1998) consider that the Isle de Cayenne Series in northern French Guiana are the high-grade equivalents of these greenstone sequences. The first evidence of Paleoproterozoic ages for these sequences was furnished by Rb-Sr and K-Ar geochronological determinations of between 2.09 and 1.97 Ga (Basei, 1973; Montalvão and Tassinari, 1984). Pb-evaporation ages of 2.22–2.17 Ga on zircon were provided by Vanderhaeghe *et al*. (1998) and Delor *et al*. (2001b) on the Isle de Cayenne complex, and a Sm-Nd age of 2.11 ± 0.90 Ga was obtained by Gruau *et al.* (1985) for the greenstone sequences in central French Guiana. The former authors

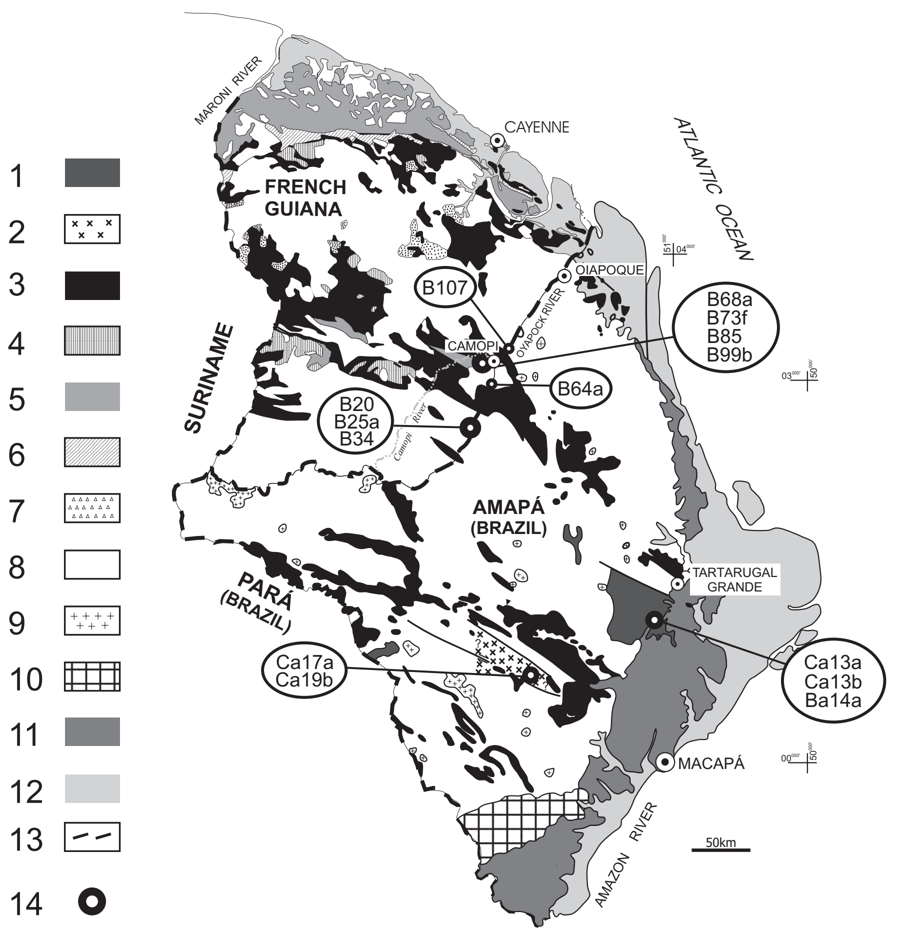

Fig. 3.- Simplified geological map of the easternmost part of the Guiana shield (French Guiana and Amapá State, Brazil). Modified from Lima *et al.* (1991) and recent work by brgm/France and CPRM/Brazil. 1. Granulite (felsic and mafic granulite), 2. Reworked Archean orthogneiss (mainly tonalite), 3. Greenstone belts (Paramaca - Vila Nova formations), 4. Mafic plutonics, 5. Flysch-like sedimentary sequences (Armina Formation), 6. Upper Sedimentary Units (sandstone and conglomerate), 7. Diorite, 8. Paleoproterozoic (”Transamazonian”) granitoid/orthogneiss, 9. Post-Transamazonian granitoid, 10. Paleozoic sediments, 11. Lateritic cover, 12. Cenozoic sediments, 13. International boundaries, 14. Sample locations. Proterozoic and Jurassic dykes are not represented.

Fig. 3.- Carte géologique simplifiée de la portion orientale du Bouclier guyanais (Guyane et état de l'Amapá, Brésil), modifiée d'après Lima et al. *(1991) et des travaux récents du brgm/France et de la CPRM/Brésil. 1. Granulites (granulites acides et basiques). 2. Orthogneiss archéens repris (tonalites dominantes), 3. Ceintures de roches vertes (formations Paramaca et Vila Nova), 4. Roches plutoniques basiques, 5. Séquences sédimentaires flyschoïdes (Formation Armina), 6. Unité sédimentaire supérieure (arénites et conglomérats), 7. Diorites, 8. Granitoïdes et orthogneiss paléoprotérozoïques (“transamazoniens”), 9. Granitoïdes post-transamazoniens, 10. Sédiments paléozoïques, 11. Couvertures latéritiques, 12. Sédiments cénozoïques, 13. Frontières internationales, 14. Localisation des échantillons. Les dykes protérozoïques et jurassiques ne sont pas représentés.*

suggest southward-decreasing ages for the greenstone belts, but this is not confirmed by the Sm-Nd age of 2264 ± 34 Ma for the Ipitinga greenstones (McReath and Faraco, 1997) located even farther south at the frontier between Amapá and Pará States in Brazil. Morever, a recent systematic dating programme associated with new mapping of the lithostructural chronology (Delor *et al*., 2001b) has determined the spatial relationships of two pulses of TTG magmatism, globally coeval with the greenstone belts. It showed that a 2.15-2.13 Ga generation occupies the central part of French Guiana and is bordered by an older 2.18-2.16 Ga generation, known in the north as the southernmost French Guiana formation. Mafic plutonic rock and diorite have also been described in French Guiana, as well as supracrustal formations that are not included in the greenstone belts -according to Milesi *et al.* (1989), these units consist of flysch-like sedimentary sequences (Armina Formation) and sandstone and conglomerate (Upper Sedimentary Unit).

The most widely represented rocks in the EGS are granitoid and orthogneiss. Excluding the tonalitic orthogneiss of the central-southern part of Amapá (Cupixi region), all the granitoid is assumed to be Paleoproterozoic in age, related to the Transamazonian orogeny. Distinction between different kinds of granitoid have been proposed according to geographical location, petrological and structural features, relationships with supracrustal sequences and, more recently, geochronological criteria (Vanderhaeghe *et al*., 1998; Rossi *et al*., 2000; Delor *et al*., 2001b). Two main phases of granitogenesis are normally recognized in the MIP (Teixeira *et al*., 1989; Gibbs and Barron, 1993). The first granitic pulse gave rise to syn-tectonic intrusions and orthogneiss, mostly of tonalitic, trondjhemitic and granodioritic (TTG) composition with high Na contents (namely the “Guyanais” granite in French Guiana, after Choubert, 1974). These granites are coeval with the main deformational event and are associated with the greenstone belts. The second granitic pulse is represented by late- to post-tectonic granite with high-K and/or calc-alkaline affinities (namely the “Caraïbes” granite in French Guiana, after Choubert, 1974). Rb-Sr and K-Ar dating of Transamazonian granite and orthogneiss provided a range of ages between 2.3 Ga and 1.8 Ga (Teixeira *et al*., 1989; Gibbs and Barron 1993; Tassinari *et al*., 2000 and references herein), but the recent systematic Pb-Pb determinations on zircon and Sm-Nd determinations on whole rock in French Guiana have significantly improved our knowledge concerning the chronology of the magmatism (Delor *et al*., 2001b; Lafon *et al*., 2002). In the northern part of French Guiana, Vanderhaeghe *et al.* (1998) noted the existence of

LITHOLOGY *(Sample)*	Latitude (N)	Longitude (W)
Samples from central Amapá		
Garnet-bearing granulite *(CA13a)*	1° 03' 16.0"	51° 05' 19.0"
Felsic granulite *(CA13b)*	1° 03' 16.0"	51° 05' 19.0"
Tonalitic orthogneiss *(CA17a)*	0° 48' 961	51° 58' 555
Tonalitic orthogneiss *(CA19b)*	0° 36' 53.0"	51° 46' 15.0"
Felsic granulite *(BA14a)*	1° 01' 45.6"	51° 05' 30.0"
Samples from southeastern French Guiana		
Quartzite (B73f)	3° 12' 42.7"	52° 27' 22.8"
Migmatitic granodiorite (B85)	3° 10' 20.3"	52° 21' 24.5"
Granite (B25a)	2° 39' 58.8"	52° 31' 30.0"
Tonalite (B107)	3° 19' 03.6"	52° 11' 05.3"
Granodiorite (B64a)	3° 04' 43.7"	52° 19' 35.5"
Granite (B34)	2° 47' 42.8"	52° 28' 10.8"
Migmatitic paragneiss (B20)	2° 46' 35.6"	52° 28' 39.9"
Garnet-bearing paragneiss *(B68a)*	3° 10' 15.2"	52° 28' 40.9"
Granite (B99b)	3° 14' 28.7"	52° 16' 13.7"

Table 1.- Coordinates of the dated samples.

Tabl. 1.- Coordonnées des échantillons datés.

early granitoid of calc-alkaline affinity (tonalite and granodiorite) associated with continental-crust accretion (2144–2115 Ma), and late crustal-derived high-K granite and peraluminuous granite related to crustal recycling (2093-2083 Ma). A U-Pb age in the same range as the early granitoid (2146 ± 2 Ma) was obtained by Lafrance *et al.* (1999) for the St-Elie granodiorite intrusion in northwestern French Guiana. In Amapá State, no distinction has yet been mapped between different phases of granite. Nevertheless, early Na-rich and late K-rich granites have been described in central Amapá (João and Marinho, 1982b) and recent U-Pb and Pb-Pb results on zircons in Amapá suggest that the Transamazonian magmatic episodes were similar in both composition and timing as those recognized in French Guiana (Nogueira *et al*., 2000; Avelar *et al*., 2001, 2002).

The thermal evolution of the Transamazonian orogeny is registered by the closure of Rb-Sr, K-Ar and Ar-Ar systems in the minerals, indicating a temperature decrease from 550 to 250 °C (Jäger *et al*., 1967; Harrison *et al*., 1985) between 2.08 Ga and 1.76 Ga (Montalvão and Tassinari, 1984; Tassinari, 1996; Nomade *et al*., 2001, 2002). Following the Transamazonian orogeny, the EGS behave as a cratonized area; no further widespread magmatic/metamorphic event has as yet been registered. Post-Transamazonian magmatic activity in Amapá is restricted to some felsic intrusions and alkaline intrusions dated respectively at about 1.76 Ga (Tassinari *et al*., 1984; Vasquez and Lafon, 2001) and 1.68–1.34 Ga (Montalvão and Tassinari, 1984). An Early Liassic dolerite dyke-swarm emplacement related to the emplacement of the Central Atlantic Magmatic Province (Courtillot and Renne, 2003) is well constrained at 198 Ma in French Guiana (Deckart *et al*., 1997). The legend of Figure 2 summarizes the main geological units exposed within the EGS (adapted from Lima *et al*. [1991], from the legend of the Geological Map of French Guiana and from recent CPRM/Brazil work).

Sample selection and description

The samples selected for zircon Pb-evaporation and Sm-Nd whole-rock dating came from southeastern French Guiana and central Amapá; the sampling locations are shown on Figure 3 and coordinates are listed in Table 1. The samples from southeastern French Guiana were collected at nine sites along a 90 km section -three along the Camopi River (B73f, B68a, B85), two along the Oyapock River downstream (B107, B99b) and four along the Oyapock River upstream (B64a, B34, B20, B25a).

The northernmost samples on the Oyapock River are a coarse-grained amphibole-biotite tonalite (B107) and a medium-grained hornblende-biotite monzogranite intruded within the Paramaca sequences (B99b). Pb-evaporation dating of zircons from the B107 tonalite furnished a well-defined age of 2163 ± 3 Ma that is considered as the crystallization age of the tonalite. This age (so far unpublished) is indicated on the last edition of the Geological Map of French Guiana (Delor *et al*., 2001b).

The three samples from the Camopi River are a quartzite (B73f) associated with the greenstone sequences, a garnet-bearing paragneiss (B68a) and a migmatitic granodiorite (B85); they were collected respectively at the “Saut Diable” falls, the “Saut Chien” falls and close to Camopi village. The

B73f quartzite shows a bedding transposed along an E-W-trending schistosity with a 30° dip to the north, and comprises mainly quartz with some hornblende, plagioclase and opaque minerals: tight fold axes are observed with a N350°/30° dip. Based on U-Th-Pb dating with the electron-probe micro-analyser (Cocherie *et al.*, 2000), the quartzite has been identified as bearing Archean zircons. Sample B68a is a fine- to medium-grained gneiss composed mainly of quartz and K-feldspar with some plagioclase, biotite and garnet phenoblasts. Sample B85 corresponds to a migmatitic granodiorite with a medium- to coarse-grained granolepidoblastic texture with a N070-090° foliation dipping 15-30° to the north. The main petrographic assemblage is alkali-feldspar, plagioclase, quartz and hornblende; chlorite, sericite, epidote, titanite, apatite and oxide minerals are accessory. In an attempt to date this sample, U-Pb zircon analyses were performed with the Cameca IMS1270 ion microprobe of the CRPG (Centre de recherches pétrographiques et géochimiques) at Nancy, France. Most of the zircons were highly discordant in the Concordia diagram, but one grain furnished a concordant value of about 2.10 Ga as an indication of the emplacement age.

Sample B64a came from a site located on the Oyapock River, immediately upstream of the Camopi River. It is a grey well-foliated metatexitic granodiorite with a porphyroblastic texture and secondary shear bands infilled by leucocratic aplite (B64b). Foliation trends in the granodiorite host rock are about N045-060° with a 30° dip to the north, and the secondary shear bands exhibit the same azimuth with a shallower dip. The secondary shear bands reflect normal faulting under ductile conditions of metamorphism along a quartzo-feldspathic mineral lineation dipping 20°N. The porphyritic texture is revealed by alkali-feldspar phenoblasts dispersed within a fine-grained matrix of quartz and feldspar. Locally, thin bands of biotite alternate with granoblastic layers. The main mineralogy consists of plagioclase, quartz, alkali-feldspar and biotite, with apatite, allanite, sericite and zircon as accessory phases. A zircon U-Pb age of 2128 ± 10 Ma (unpublished) was obtained for the emplacement of the B64a granitoid, using the CRPG´s IMS1270 ion microprobe. The age of the B64b aplitic type material is unknown, but is assumed to be *ca.* 2100 Ma, in relation to the main melting event of the B64a TTG-related crust producing new granitic suite magmatism. As for samples B107 and B85, this age is indicated on the Geological Map of French Guiana (Delor *et al*., 2001b).

Sample B34 comes from porphyritic granite intrusive within the volcano-sedimentary sequences. The rock is medium-grey or pink and leucocratic, being composed of alkali-feldspar and quartz phenocrysts within a grey matrix. The main paragenesis is alkali-feldspar, quartz and plagioclase, with accessory epidote, chlorite, apatite and zircon.

Sample B20 is a migmatitic paragneiss within the Paramaca volcano-sedimentary sequence. It displays a medium-grained lepidoblastic texture, marked by biotite orientation forming a N100°-trending foliation with a shallow northerly dip. The main mineralogy is alkali-feldspar, plagioclase, quartz, biotite and rare hornblende, commonly altered to biotite or epidote. Titanite, epidote, carbonate minerals, apatite and zircon appear as accessory phases.

Sample B25a, from the southernmost sampling site on the Oyapock River, represents a hypabyssal leucosyenogranite that trends N145° with a 75° northeasterly dip, and crosscuts tonalitic and granodioritic orthogneiss. The mineralogical composition includes microcline, perthitic orthoclase, quartz, plagioclase and accessory minerals such as sericite, chlorite, epidote, apatite, opaque minerals and zircon.

In central Amapá, samples were taken of granulite (CA13a, CA13b, BA14a) in the Tartarugal Grande region and tonalitic orthogneiss (CA17a, BA19b) in the Cupixi region (Fig. 3). The granulite samples correspond to charnockite and enderbite included in the Ananai metamorphic suite and previously dated at 2450 ± 74 Ma by the Rb-Sr method (João and Marinho, 1982a). Samples CA13a and CA13b came from the same outcrop and Sample BA14a was collected a few kilometres farther south. CA13a is a garnet-bearing felsic granulite with a medium-grained granoblastic texture. Its mineral paragenesis consists of dominant K-feldspar, quartz, plagioclase, biotite, amphibole and garnet; opaque minerals, sericite, muscovite and clay minerals are also present. CA13b is a felsic granulite with chanockitic composition and has the same textural feature as the CA13a granulite. Its main minerals are quartz, K-feldspar, orthopyroxene, plagioclase and biotite; opaque minerals, zircon and sericite are accessory. Despite the fact that this sample came from the same outcrop as CA13a, no contact relationships have been observed.

Sample BA14a is from a fine- to medium-grained felsic granulite that displays a strong foliation enhanced by subhorizontal veins as a result of *in situ* melting. The veins trend N150° and dip 15° W. The mineralogical assemblage consists of alkali-feldspar, quartz, plagioclase and garnet; zircon and opaque minerals are accessory phases. Unpublished zircon U-Pb SHRIMP data and monazite U-Th-Pb EPMA data suggest ages of *ca*. 2.60 Ga for the crustal-derived protolith of this granulite, and *ca*. 2.06 Ga for the *in situ* melting episode.

Samples CA17a and CA19b were collected at two sites separated about 20 km apart. Both samples are tonalitic orthogneiss with a protomylonitic texture trending NNW-SSE. The paragenesis of the CA19b tonalite comprises plagioclase, quartz, orthoclase and hornblende. Hornblende was not observed in sample CA17a, but biotite and muscovite are present. Accessory minerals in both samples are chlorite, sericite, apatite and zircon. The presence of anatectic mobilizates with a granitic composition at both sites is evidence of migmatization, and the two samples are considered as paleosomes of the migmatite. Rb-Sr and Sm-Nd dating on similar rocks from the same area provided ages of about 2.9–3.0 Ga (Montalvão and Tassinari, 1984; Sato and Tassinari, 1997).

Geochronological results

Experimental Procedures

Zircon extraction was done at the BRGM laboratory in Orleans, France, for samples B68a and CA17a, and at the Geosciences Center of the UFPa (Federal University of Pará), Belém, Brazil for samples CA13a, C13b and B73f.

Zircons from samples CA17a, CA13a, CA13b and B73f were then dated by the evaporation method (Kober, 1986, 1987) at the UFPa geochronological laboratory (Pará-Iso). The isotope analyses were performed on a Finnigan MAT262 mass spectrometer in dynamic mode, using the ion counting detector. $^{207}Pb/^{206}Pb$ 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; analyses with $^{206}Pb/^{204}Pb$ ratios lower than 2500 were discarded. Common Pb corrections were done using the Stacey and Kramers (1975) model.

Sample B68a was analysed with a Finnigan MAT261 mass spectrometer at the Geochronological Laboratory of BRGM (France) according to the experimental procedure described in Cocherie *et al*. (1992). The weighted mean and corresponding errors on the ages for all samples were calculated according to Gaudette *et al*. (1998). The errors on the age are quoted at a 2σ level.

Sm-Nd isotopic analyses of samples CA13a, CA13b, CA17a and CA19b were carried out at the Belém Laboratory, and those for the other samples were done at the BRGM laboratory. In both cases, the isotopic measurements were performed on a Finnigan MAT262 multicollector mass spectrometer in static mode, although using Re double filaments at the BRGM laboratory and Ta–Re double filament at the Belém laboratory. The chemical separations a) of REE from other elements, and b) of the elements Sm and Nd, are described in Klein *et al*. (2002) for the Belém procedure and in Feybesse *et al.* (1998) for the BRGM procedure. The mean $^{143}Nd/^{144}Nd$ values obtained on repeated analyses of the La Jolla Standard during the studies were 0.511833 ± 31 (2σ, n = 13) and 0.511843 ± 24 (2σ, n = 12), respectively. Nd T_{DM} model ages for all the samples were calculated using the DePaolo (1981) model for a depleted mantle.

Pb isotopic data

The isotopic results are presented in Table 2. Zircons from the B73f quartzite are generally clear and brown, without any metamictic features. Although some of the grains are oval or rounded, elongate prismatic crystals with preserved faces are also present, revealing that part of the zircon population did not undergo a complex evolution and probably came from near the site of deposition. The $^{207}Pb/^{206}Pb$ ages obtained on the higher temperature steps are spread between 2.77 Ga (grain no. 10) and 3.19 Ga (grain no. 19). These ages are interpreted as crystallization ages and reflect a mixture of zircons from Archean sources of different ages. No Paleoproterozoic age was recorded in the analysed zircon population.

Zircons from the B68a paragneiss are small and rounded. Because of their small size and the scarcity of crystals in the sample, it was difficult to obtain reliable isotopic results. Only two out of the six grains provided a Pb signal of sufficient intensity to determine precisely the $^{207}Pb/^{206}Pb$ ratios. Grain ZrC gave one step of Pb evaporation at 1480 °C with an age of 2015 ± 44 Ma, and a second step at 1500 °C that provided an age of 2554 ± 27 Ma (Fig. 4a); these are respectively interpreted as a minimum age for the granite crystallization and as a minimum age for the source of an inherited Pb component. The second grain furnished isotopic results at only one temperature step (1480 °C). During a first set of isotopic determinations, we observed a variation of the isotopic $^{207}Pb/^{206}Pb$ ratios, which provoked a decrease of the corresponding ages from *ca.* 2.85 to 2.59 Ga (Fig. 4b). As the analysed Pb corresponds to the same heating step, its isotopic composition is assumed to be homogeneous and should not exceed significantly the analytical variations. This surprising behaviour suggests a laminar deposition of Pb during the evaporation step. As the “oldest” Pb (supposedly corresponding to the most stable / internal parts of the grain) is obtained at the beginning of Pb extraction and isotopic measurement on the ionization filament, we propose that this Pb extraction is the reverse of its deposition on the ionization filament through evaporation from the grain. After the first set of analyses, more Pb was available on the ionization filament and we repeated the isotopic measurements. The new set of results furnished an age of 2605 ± 10 Ma and no significant isotopic variation was observed (Fig. 4b). The best way to explain such a behaviour is to consider that the inherited Pb component is dominant in the grain and heterogeneously distributed. The small size of the crystal and the continuous variation of the isotopic composition of Pb during evaporation did not permit homogenization of Pb on the ionization filament.

Zircons from the CA13a garnetiferous granulite are yellow to brown and euhedral. Nine crystals were analysed

Zircon	Temp. T°C	Number of ratios	206Pb/ 204Pb	208Pb/ 206Pb	2σ	207Pb*/ 206Pb*	2σ	Age (Ma) Step	2σ	Age (Ma) Grain	2σ
Quartzite from the Camopi river (Sample B73 F)											
B73f/1	*1425*	*9*	*66667*	*0,04042*	*31*	*0,21460*	*53*	*2941*	*4*		
	1475	84	83333	0,03485	15	0,21690	24	2958	2		
	1500	38	83333	0,03193	12	0,21683	29	2958	2	**2958**	**1**
B73f/2	*1425*	*86*	*333333*	*0,03193*	*13*	*0,20601*	*35*	*2875*	*3*		
	1475	84	500000	0,03136	10	0,20738	37	2886	3		
	1500	9	> 1000000	0,03118	31	0,20769	94	2888	7	**2885**	**2**
B73f/3	1485	85	5376	0,05484	4	0,20354	50	2855	4	**2855**	**4**
B73f/4	1475	9	142857	0,17578	166	0,20054	87	2831	7		
	1525	9	> 1000000	0,20780	299	0,19931	190	2821	16	**2829**	**8**
B73f/5	1475	9	> 1000000	0,05446	479	0,24725	840	3168	54		
	1500	6	> 1000000	0,02248	33	0,24569	281	3158	18	**3159**	**17**
B73f/6	1475	82	3846	0,10456	29	0,23222	31	3068	2	**3068**	**2**
B73f/7	*1425*	*8*	*10989*	*0,03104*	*101*	*0,18157*	*212*	*2667*	*19*		
	1475	*88*	*35714*	*0,06880*	*44*	*0,20110*	*61*	*2836*	*5*		
	1566	98	111111	0,10179	24	0,20283	43	2849	3	**2849**	**3**
B73f/8	*1425*	*41*	*2793*	*0,09976*	*38*	*0,20522*	*82*	*2869*	*7*		
	1475	84	31250	0,19449	130	0,22708	31	3032	2	**3032**	**2**
B73f/9	1475	86	1000000	0,11918	40	0,20890	37	2897	3		
	1550	88	29412	0,12564	47	0,20922	42	2900	3	**2898**	**2**
B73f/10	*1450*	*89*	*16667*	*0,32817*	*262*	*0,1883*	*32*	*2728*	*3*		
	1510	25	125000	0,43113	193	0,19313	55	2769	5	**2769**	**5**
B73f/11	*1450*	*67*	*16393*	*0,13288*	*39*	*0,21464*	*41*	*2941*	*3*		
	1490	8	76923	0,15640	121	0,22316	125	3004	9	**3004**	**9**
B73f/17	1480	16	58824	0,20224	238	0,24062	135	3124	9	**3124**	**9**
B73f/18	*1450*	*73*	*3012*	*0,11565*	*29*	*0,20287*	*48*	*2850*	*4*		
	1500	42	3115	0,14900	68	0,2126	61	2926	5	**2926**	**5**
B73f/19	1485	89	25641	0,14427	74	0,24949	44	3180	2	**3180**	**2**
B73f/20	1523	9	> 1000000	0,17666	301	0,25091	182	3191	11	**3191**	**11**
B73f/21	*1450*	*87*	*71429*	*0,10938*	*19*	*0,20583*	*23*	*2873*	*2*		
	1500	87	500000	0,12129	34	0,20889	37	2897	3	**2898**	**2**
B73f/23	1500	34	16129	0,10766	134	0,20314	13	2852	10	**2852**	**10**
B73f/24	1500	54	6250	0,12869	231	0,21855	185	2970	14	**2970**	**14**
B73f/27	1500	36	16129	0,04151	129	0,13781	660	2200	83		
	1550	90	13699	0,03229	123	0,13667	520	2186	66	**2177**	**59**
Syenogranite from he Camopi river (Sample B68)											
B68/ZRC	*1480*	*37*	*1399*	*0,06768*	*88*	*0,12403*	320	*2015*	*44*		
	1500	38	1633	0,11317	47	0,16973	256	2554	27	**2554**	**27**
B68/ZRF	1480	49	3245	0,12229	349	0,18978	764	2741	64	**(2,87-2,65 Ma)**	
		46	4176	0,10073	46	0,174891	212	2605	10		

Table 2.- Zircon Pb-evaporation isotopic results for the EGS samples. Values in italics were not included in the age calculation of the grain.

Tabl. 2.- Résultats isotopiques par évaporation du Pb de zircon pour les échantillons de l'EGS. Les valeurs en italiques n'ont pas été prises en compte pour le calcul de l'âge des grains.

Garnet bearing charnockite from Central Amapá (Sample CA13a)

CA13a/2	*1450*	*90*	*6329*	*0,226420*	*54*	*0,16464*	*79*	*2504*	*8*		
	1485	16	4065	0,27051	337	0,17192	177	2577	17	**2577**	**17**
Ca13a/3	1480	88	4464	0,24888	132	0,16651	29	2523	3		
		16	2538	0,25221	124	0,16532	79	2511	8	**2522**	**8**
Ca13a/9	*1450*	*18*	*2994*	*0,22818*	*539*	*0,15071*	*158*	*2354*	*18*		
	1485	16	200000	0,30838	212	0,16882	57	2546	6	**2546**	**6**
Ca13a/10	1485	48	200000	0,28208	89	0,16776	43	2536	4		
		72	40000	0,28070	73	0,16773	3	2535	3	**2534**	**4**
Ca13a/11	*1450*	*86*	*3704*	*0,13428*	*38*	*0,13973*	*61*	*2224*	*8*		
	1485	*88*	*18519*	*0,20682*	*53*	*0,16567*	*23*	*2515*	*2*		
	1580	78	33333	0,19963	134	0,16683	23	2526	2	**2526**	**2**
Ca13a/12	*1450*	*18*	*2778*	*0,22840*	*234*	*0,15087*	*95*	*2356*	*11*		
	1500	84	10989	0,26220	73	0,16308	71	2488	7	**2488**	7
Ca13a/14	1500	95	9346	0,30348	47	0,169	19	2548	2	**2548**	**2**
Ca13a/16	1452	18	3448	0,24951	181	0,16752	116	2533	12	**2533**	**12**
Ca13a/17	1500	9	3546	0,26471	135	0,16360	60	2493	6	**2493**	**6**

Felsic granulite from Central Amapá (Sample CA13b)

CA13b/5	1500	88	15873	0,22627	133	0,15815	29	2436	3	**2436**	**3**
CA13b/6	1550	18	5051	0,24015	133	0,15511	61	2403	7		
		52	5882	0,23864	80	0,15495	53	2402	6	**2402**	**4**
CA13b/7	1530	34	3195	0,28528	118	0,16314	141	2489	15	**2489**	**15**
CA13b/8	1500	80	3236	0,20471	92	0,14915	27	2337	3	**2337**	**3**
CA13b/9	*1500*	*88*	*1471*	*0,22147*	*149*	*0,16074*	*72*	*2464*	*8*		
	1550	88	18519	0,23918	63	0,16519	39	2510	4		
		20	23810	0,24051	83	0,16512	33	2509	3	**2509**	**3**
CA13b/10	1550	36	6369	0,25904	229	0,16481	73	2506	7	**2506**	7
Ca13b/11	*1450*	*88*	*2770*	*0,11247*	*131*	*0,12729*	*40*	*2061*	*5*		
	1500	90	7407	0,21293	61	0,15640	50	2417	5	**2417**	5
CA13b/12	*1500*	*18*	*5988*	*0,22829*	*153*	*0,16041*	*90*	*2460*	*9*		
	1550	18	4386	0,27847	168	0,17046	74	2563	7	**2563**	7
CA13b/13	*1450*	*54*	*3663*	*0,19348*	*87*	*0,14568*	*28*	*2296*	*3*		
	1485	*88*	*12658*	*0,27162*	*189*	*0,17006*	*46*	*2559*	*5*		
	1550	90	15385	0,31627	73	0,17201	25	2578	2	**2578**	**2**
CA13b/16	*1485*	*30*	*9901*	*0,18227*	*115*	*0,13080*	*79*	*2109*	*11*		
	1550	82	29412	0,27883	64	0,16144	29	2471	3	**2471**	**3**
CA13b/17	1485	52	4464	0,27621	115	0,16577	49	2516	5	**2516**	5

Tonalitic orthogneiss fromCupixi region (Sample CA17a)

CA17a/4	*1485*	*36*	*3891*	*0,08643*	*52*	*0,17468*	*97*	*2603*	*9*		
	1535	70	5348	0,11490	282	0,20349	48	2855	4	**2855**	**4**
CA17a/1a	*1475*	*90*	*3546*	*0,08018*	*50*	*0,18124*	*28*	*2664*	*3*		
	1500	16	45455	0,14562	102	0,20304	162	2851	13	**2851**	**13**
CA17a/9a	1550	86	8403	0,16041	124	0,20232	42	2845	3	**2845**	**3**
			Mean CA17a/4 + CA17a/1a + CA17a/9a (USD: 2,6)							**2849**	**6**

Tabl. 2.- Suite/Continued

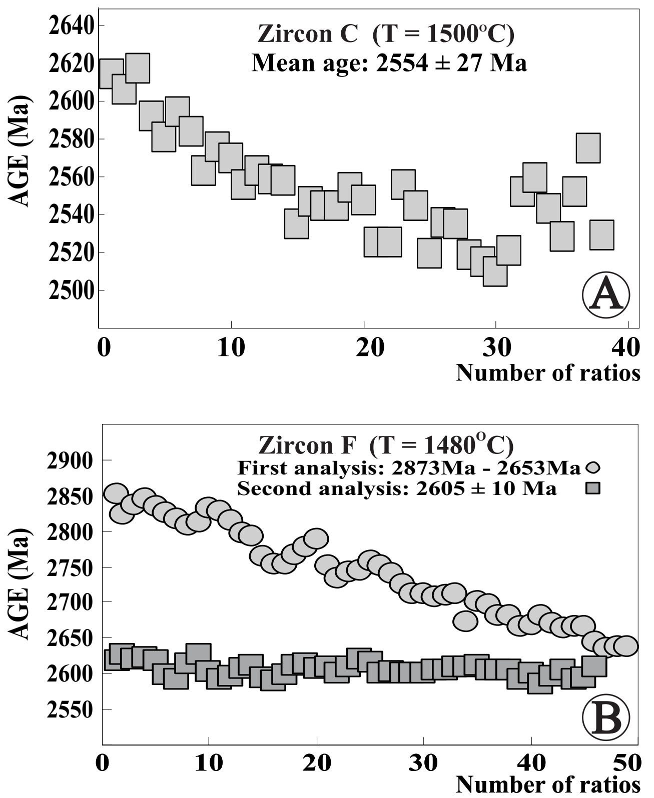

Fig. 4.- Spectrum of Pb-evaporation ages on zircon from paragneiss sample B68a. (A): 1500 °C heating step of zircon C. (B): 1480 °C heating step of zircon F. Each point corresponds to one $^{207}Pb/^{206}Pb$ measurement.

Fig. 4.- Spectre d'âges par évaporation de plomb sur zircon de l'échantillon de paragneiss B68a. (A): Palier de température de 1500°C du zircon C. (B): Palier de température de 1480°C du zircon F. Chaque point correspond à une mesure du rapport $^{207}Pb/^{206}Pb$.

and gave ages between 2488 ± 7 and 2577 ± 17 Ma. This variation of about 90 Ma is too large to enable a good estimate of the age of grain crystallization. Some crystals gave the same age at different steps of heating (e.g. grains 3, 10 and 11) but with different ages from one grain to another one. As no reproducible ages were obtained on the analysed population, the oldest age is considered as a minimum age for the zircon crystallization. The euhedral shape of the crystals suggests that the zircons retained their magmatic features; the age is thus considered as the minimum age of the protolith rather than the age of high-grade metamorphic event. No evidence of Transamazonian age was indicated out by these analyses.

The zircons from the orthopyroxene-bearing granulite CA13b are also elongate euhedral crystals; careful microscopic observation revealed no metamictic feature. The analysed grains are clear and brown, similar to those from Sample CA13a. Eleven grains were analysed and gave widespread $^{207Pb/206}$Pb ages between 2337 ± 3 Ma (CA13b/8) and 2578 ± 2 Ma (CA13b/13). As with the previous sample, the isotopic data do not enable a well-defined age to be obtained for the granite crystallization. The wide spread of the data (241 Ma) is much larger than for Sample CA13a (89 Ma) but the oldest ages in the two samples are the same (2.58 Ga). The similarity between these ages suggests that this value could represent the crystallization age of both samples, but as only one grain in each sample provided the 2.58 Ga age, we prefer to consider this age as a minimum, according to what has been observed on the same kind of rocks in previous studies (Paquette *et al*., 1994; Jaeckel *et al*., 1997). Once again, the zircons do not show any metamorphic feature and the age is interpreted in terms of a magmatic rather than a metamorphic age. On some grains (nos. 10 and 16) the low temperature steps provided a Paleoproterozoic age of between 2.05 and 2.15 Ga; this may correspond to a resetting of the U-Pb chronometer during the Transamazonian event, although the influence of that event on the studied sample remains limited.

Only three grains of the CA17a tonalitic orthogneiss provided a sufficiently intense signal to obtain isotopic measurements in the mass spectrometer. The main value of the isotopic results furnished by the highest heating steps of the three grains (i.e. 1535 °C, 1500 °C and 1550 °C, respectively) gave an age of 2849 ± 6 Ma. The fact that no Paleoproterozoic age was obtained, even at the lower temperature steps, strongly suggests that the age of 2.85 Ga corresponds to the crystallization age of the magmatic protolith.

Sm-Nd isotopic data

The Sm-Nd results are given in Table 3, which also includes initial εNd values calculated at the estimated emplacement age provided by Pb evaporation, when available -this is the case for samples B107 and B64a from southeastern French Guiana and for samples CA13a, CA13b, BA14a and CA17a samples from central Amapá. The emplacement/formation ages for the other samples from southeastern French Guiana were assumed to be *ca*. 2.1 Ga, whereas for central Amapá, it was assumed that Sample CA19b is coeval with the tonalitic orthogneiss CA17a. As all the samples showed $^{143}Nd/^{144}Nd$ ratios in the range of 0.08 to 0.13, the data are useful for model age calculation. Granulite and tonalitic orthogneiss samples from the central Amapá region furnished Nd T_{DM} model ages of 2.90 to 3.29 Ga, with εNdi between -6.00 and +1.01 (Table 3). These values are within the 3.06–3.10 Ga range of Nd T_{DM} model ages previously obtained on Cupixi orthogneiss by Sato and Tassinari (1997). Recently, Pimentel *et al*. (2002) obtained Nd T_{DM} model ages between 3.07 and 3.36 Ga for the orthogneissic country rocks of the Paleoproterozoic mafic-ultramafic Bacuri Complex, which also occurs in central Amapá. This large range of Nd ages suggests heterogeneities in the sources of the metamorphic rocks, as well as a protracted period of crustal differentiation from mantle sources during the Mesoarchean. The set of Sm-Nd results in central Amapá

LITHOLOGY *(Sample)*	Sm (ppm)	Nd (ppm)	$f_{(Sm/Nd)}$	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd$	$\varepsilon_{(0)}$	Age* (T_{Ga})	$\varepsilon_{(T)}$	T_{DM} (Ga)	Ref.
Samples from central Amapá										
Garnet-bearing granulite *(CA13a)*	4.11	22.00	-0.425	0.1130	0.510909 ± 6 (1σ)	-33.73	2.58	-6.00	3.29	(1)
Felsic granulite *(CA13b)*	3.33	24.60	-0.584	0.0819	0.510544 ± 8 (1σ)	-40.85	2.58	-2.76	2.92	(1)
Tonalitic orthogneiss *(CA17a)*	1.72	11.16	-0.525	0.0934	0.510747 ± 16 (1σ)	-36.89	2.85	1.01	2.94	(1)
Tonalitic orthogneiss (CA19b)	3.10	17.12	-0.448	0.1085	0.511026 ± 6 (1σ)	-31.45	2.85	0.92	2.96	(1)
Felsic granulite (BA14a)	1.93	14.40	-0.588	0.0810	0.510542 ± 5 (2σm)	-40.89	2.60	-2.04	2.90	(1)
Granite *(EG18)*	7.14	52.17	-0.519	0.0828	0.510443 ± 18 (1σ)	-42.82	2.90	-0.28	3.06	(2)
Tonalite *(EG02)*	7.18	46.68	-0.556	0.0874	0.510508 ± 32 (1σ)	-41.55	2.90	-0.73	3.10	(2)
Gneiss (Sm-03/80.4)	4.54	27.76	-0.497	0.0989	0.510737 ± 8 (1σ)	-37.08	-	-	3.07	(3)
Gneiss (Sm-03/87.2)	3.61	17.67	-0.372	0.1235	0.511071 ± 10 (1σ)	-30.57	-	-	3.36	(3)
Gneiss (Sm-03/72.5)	4.95	24.63	-0.382	0.1216	0.511128 ± 7 (1σ)	-29.46	-	-	3.19	(3)
Gneiss (Sm-03/52.0)	2.37	13.77	-0.471	0.1041	0.510752 ± 5 (1σ)	-36.79	-	-	3.20	(3)
Samples from southeastern French Guiana										
Migmatitic granodiorite (B85)	11.4	61.8	-0.435	0.1111	0.511543 ± 5 (2σm)	-21.36	2.10	1.74	2.24	(1)
Granite (B25a)	5.84	34.4	-0.478	0.1026	0.511417 ± 4 (2σm)	-23.82	2.10	1.57	2.24	(1)
Tonalite (B107)	4.72	21.9	-0.338	0.1303	0.511777 ± 6 (2σm)	-16.80	2.16	1.64	2.32	(1)
Granodiorite (B64a)	6.57	32.2	-0.374	0.1232	0.511653 ± 6 (2σm)	-19.21	2.13	0.62	2.35	(1)
Granite (B34)	0.96	5.98	-0.507	0.0969	0.511241 ± 3 (2σm)	-27.25	2.10	-0.33	2.36	(1)
Migmatitic paragneiss (B20)	12.3	83.4	-0.547	0.0892	0.511084 ± 4 (2σm)	-30.31	2.10	-1.32	2.41	(1)
Garnet-bearing paragneiss *(B68a)*	3.23	17.53	-0.434	0.1113	0.511405 ± 6 (2σm)	-24.05	2.10	-1.02	2.45	(1)
Granite (B99b)	3.06	17.3	-0.454	0.1073	0.511256 ± 3 (2σm)	-26.96	2.10	-2.86	2.58	(1)

Table 3.- Whole rock Sm-Nd isotopic data on granulites, granitoids and gneisses from central Amapá and southeastern French Guiana. (1) this work; (2) Sato and Tassinari (1997); (3) Pimentel *et al*. (2002). T_{DM} ages were calculated using the DePaolo (1981) model for Nd evolution of the depleted mantle. *: Crystallization ages determined by zircon Pb-Pb or U-Pb and Rb-Sr dating were used, when available, for calculation of the initial $\varepsilon_{(Nd)}$; otherwise the age was arbitrarily assumed, except for the Sm-03 gneiss samples for which either a Paleoproterozoic or an Archean age is possible.

Tabl. 3.- Données isotopiques Sm-Nd sur roche totale pour les granulites, les granitoïdes et les gneiss de la région centrale de l'Amapá et le sud-est de la Guyane. (1) cette étude; (2) Sato et Tassinari (1997); (3) Pimentel et al. *(2002). Les âges modèles T_{DM} ont été calculés selon le modèle de DePaolo (1981) pour l'évolution du Nd dans le manteau appauvri. *: Les âges de cristallisation déterminés par les méthodes Pb-Pb ou U-Pb sur zircon et Rb-Sr ont été utilisés, lorsque ceux-ci sont disponibles, pour le calcul de la valeur initiale de $\varepsilon_{(Nd)}$; Pour les autres échantillons, une valeur arbitraire de l' âge a été utilisée sauf dans le cas des échantillons de gneiss Sm-03 pour lesquels un âge soit archéen soit paléoprotérozoïque est possible.*

indicates a similar period of crust-mantle differentiation as in the Carajás Province, despite the scarcity of the Nd T_{DM} model ages in both regions.

The granitoid and paragneiss rocks from the Camopi and Oyapock rivers can be divided into two groups according to their Nd T_{DM} model ages and initial ε_{Ndi}. Four samples of granitoid (B107, B64a, B85, B25a) provided Nd T_{DM} model ages between 2.24 and 2.35 Ga, with positive initial εNdi values of 0.62 – 1.74 indicating that these rocks were derived from a juvenile Eo-Transamazonian mantle source. The other four samples of granite (B99b, B34) and paragneiss (B20, B68a) yielded Nd T_{DM} model ages between 2.36 and 2.58 Ga with negative initial ε_{Ndi} values of -0.33 – -2.86. These Nd T_{DM} model ages, in combination with older inherited Pb-Pb ages of up to 2.85 Ga obtained on zircons from the garnet-bearing paragneiss (sample B68a), are interpreted in terms of mixing between an older Archean continental source (*ca.* 3.0 Ga) and a Paleoproterozoic juvenile magmatism at about 2.1 Ga, rather than in terms of a 2.36-2.58 Ga accretion episode, as illustrated in Figure 5.

Discussion

The Pb-Pb and Sm-Nd isotopic results, obtained on meta-igneous and metasedimentary rocks from central Amapá State and southeastern French Guiana, provide definitive evidence for the existence of Archean remnants in the Paleoproterozoic crust of the EGS. They confirm the assumption provided by previous Rb-Sr and Sm-Nd data (João and Marinho, 1982a; Montalvão and Tassinari, 1984; Sato and Tassinari, 1997) and enable us to discuss some important questions concerning the crustal evolution of the EGS.

What are the nature and extension of the Archean remnants with respect to the juvenile crustal domains in the EGS? Do they occur as reworked Archean material, as isolated Archean relics or as preserved Archean nuclei?

Are the Archean relics of the same age as the Archean Carajás Province, and do they correspond to its northward extension?

Is the high-grade metamorphic episode Archean or Paleoproterozoic in age, or both?

Extension and nature of the Archean remnants

To discuss the geodynamic models proposed for the crustal evolution of the EGS, it is important to determine the extension of the Archean remnants and to define whether they consist of isolated Archean relics or represent an extended Archean basement reworked by Transamazonian orogeny. However, one must take into

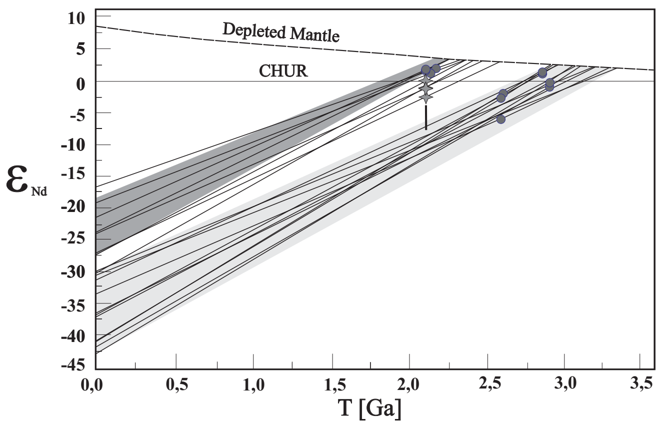

Fig. 5.- $\varepsilon_{(Nd)}$ vs. Nd model age diagram for the EGS samples. The Nd evolution ranges for Archean and Paleoproterozoic crust are also shown. The Nd evolution area of the Paleoproterozoic crust has been calculated assuming mantle extraction ages of 2.25 Ga and 2.15 Ga with $^{147}Sm/^{144}Nd$ = 0.09 - 0.12. The $\varepsilon_{(Nd)}$ values at 2.10 Ga for samples B68a, B99b, B34 and B20 correspond to Paleoproterozoic and Archean mixed sources, as indicated by the black arrow, following the model of Arndt and Goldstein (1987).

Fig 5.- Diagramme $\varepsilon_{(Nd)}$ vs. âge modèle Nd pour les échantillons de l'EGS. Les domaines d'évolution isotopique du Nd de la croûte archéenne et paléoprotérozoïque sont également montrés. Le domaine d'évolution du Nd de la croûte paléoprotérozoïque a été calculé en considérant des âges d'extraction du manteau entre 2,25 Ga et 2,15 Ga pour des rapports $^{147}Sm/^{144}Nd$ entre 0,09 et 0,12. Les valeurs de $\varepsilon_{(Nd)}$ à 2,10 Ga pour les échantillons B68a, B99b, B34 et B20 correspondent à des mélanges de sources archéenne et paléoprotérozoïque, comme l'indique la flèche noire, selon le modèle de Arndt et Goldstein (1987).

account the fact that any definitive answer on this point is hampered by the scarcity of field-constrained geochronological data and the limitations of the Pb evaporation method for discriminating crystallization ages and inherited lead-component ages in zircons that have undergone a complex history.

French Guiana

In French Guiana, all the previously dated units, as well as the zircon ages obtained during the recent BRGM geological mapping programme, indicate only Proterozoic crystallization ages for the magmatic rocks (Gruau *et al.*, 1985; Teixeira *et al.*, 1984, 1985, 1989; Venderhaegue *et al.*, 1998; Delor *et al.*, 2001b; Lafon *et al.*, 2002). Field evidence demonstrated that the quartzite and the paragneiss and granitoid from the Camopi and Oyapock rivers are at least as young as the Paleoproterozoic greenstone belt (Delor *et al.*, 2001b). In southeastern French Guiana, therefore, an Archean signature is registered only in detrital zircons from the B73f quartzite and as an inherited lead component in zircon from the B68a paragneiss. Such an inheritance is confirmed by the Nd T_{DM} model ages in the granitoid and paragneiss that were derived from crustal anatexis and that have been slightly to highly affected by mixing processes between Paleoproterozoic juvenile and Archean inherited components. Thus the existence of preserved Archean nuclei has not been yet identified here.

Central Amapá

In central Amapá, the dated zircons came from high-grade metamorphic rocks of igneous origin and so the Pb-evaporation ages represent either magmatic or metamorphic ages. No Transamazonian age was found, even in the highest heating step of all the analysed zircons, which strongly suggests that the Archean evaporation ages represent crystallization or recrystallization ages rather than an inherited Archean Pb component in the Paleoproterozoic zircons. Ricci *et al*. (2001) and Rosa Costa *et al*. (2001, 2003) have presented new geochronological results, obtained during the Renca Promin Project at the frontier between Amapá and Pará States, which clearly reinforce the existence of large 2.80–2.58 Ga old Archean nuclei reworked by the Transamazonian orogeny.

Archean - Proterozoic boundary in the EGS: extension and shape

The ages obtained on the quartzite and metagranitoid from the Camopi River indicate that the occurrence of Archean recycled components is not limited to the central Amapá region and that it can be extended up to the southeastern part of French Guiana. Tassinari (1996) considered that the EGS can be divided into two domains separated by the Oyapock River: a southern domain with sialic characteristics and a northern domain with juvenile simatic characteristics. Our geochronological results, together with the available set of radiometric data on French Guiana (Vanderhaeghe et al., 1998; Delor et al., 2001b), have led to the same conclusion on the existence of two crustal domains. However, the boundary lies farther north than in Tassinari's proposal of the Oyapock River, with a trend more likely to be WNW-ESE rather than NE-SW. This option (Delor *et al*, 2001b, 2003) also takes into account the presence of Archean ages in Amapá, on both the western and eastern sides of the Oyapock axis extended to the south. Morever, such boundary does not correspond to a sharp mappable contact, but rather to a transitional progressive zone.

Archean stages and relationships with the Carajás Province

Our results also provide data for reconsidering the boundary between the Archean Carajás Province and the Paleoproterozoic Maroni-Itacaiúnas Province.

Previous results

Cordani *et al.* (1979) suggested that the boundary between these two provinces is located at the northern limit of the Carajás range. This proposal supported the geotectonic model for the Amazonian Craton, an up-to-date version of which was presented by Tassinari and Macambira

(1999). Santos *et al.* (2000), however, proposed that the boundary between Archean and Paleoproterozoic domains was in the central Amapá area. The lack of geochronological studies in the sector between the Carajás region and central Amapá region means that we cannot provide any definitive conclusion on this point. However, the existence of Paleoproterozoic Rb-Sr ages in metamorphic rocks of the Altamira region (Santos *et al*., 1988), northwest of Carajás, as well as the zircon Pb-Pb age of 2.07 Ga for a calc-alkaline granite intrusion in the north of Carajás (Macambira *et al*., 2001) indicate that the fingerprinting of the Transamazonian orogeny is detectable to as far as the south of the Amazon Basin.

This study

Mesoarchean. The ages obtained on zircons from the Camopi quartzite range between 2.77 and 3.19 Ga, which corresponds roughly to the age of the main evolution of the Carajás Province, which is the only Archean domain in the Amazonian Craton preserved from Paleoproterozoic reworking. This is a strong indication that the Carajás Mesoarchean – Neoarchean crust may have constituted a more extended domain than that actually preserved. The minimum age of 2.87-2.85 Ga obtained on Samples B68a and CA17a also reinforces the existence of Mesoarchean crust in Amapá State and the southeastern part of French Guiana. These results are in good agreement with the previous Rb-Sr age of *ca.* 2.90 Ga obtained for the tonalitic orthogneiss by Montalvão and Tassinari (1984). The T_{DM} ages between 3.36 and 2.90 Ga also reinforce the similarities with the Carajás region, where the major period of crustal accretion from the mantle was between 3.10 and 2.87 Ga (Macambira and Lafon, 1995; Cordani and Sato, 1999; Tassinari and Macambira, 1999; Souza *et al.*, 2001).

Neoarchean. The Pb-Pb and U-Pb ages of *ca*. 2.58-2.60 Ga obtained on three samples of granulite from the Tartarugal Grande region, even if considered as minimum ages for the protolith crystallization, indicate a Neoarchean magmatic episode poorly recognized in the Carajás Province, where volcanism and sedimentary deposition predominated during this period (Macambira and Lafon, 1995; Trendall *et al*., 1998; Tassinari *et al*., 2000). Ages in the 2.58 - 2.40 Ga bracket have been obtained only in the northern part of the Carajás Province, mainly for a few small granite plutons and for a late-K metasomatic event that affected the basement units (Machado *et al*., 1991; Souza *et al*., 1995). The existence of this episode is reinforced by the 2.58 ages obtained in granulitic rocks from the Renca Project area (Ricci *et al*., 2001; Rosa Costa *et al*., 2001, 2003). These results thus provide a first evidence that the segment of Archean crust involved in the EGS underwent a different history than that of the Carajás Province and that it was subjected to a younger Neoarchean event while the Carajas Province behaved as a stable crustal segment.

Age of the high grade metamorphism

The age of the high-grade metamorphic event in central Amapá is still under debate. João and Marinho (1982a) discussed the metamorphic evolution of the area and, on the basis of the Rb-Sr age of 2.45 Ga, suggested that the high-grade metamorphic event took place during the Archean. The 2.58 Ga age obtained on two samples of granulite point to an Archean age for the magmatic protoliths, but do not constrain the age of the metamorphism. No evidence of a Transamazonian overprinting has been registered in the U-Pb system of the zircons, which suggests that the granulitic event may be Archean in age. However, Oliveira *et al*. (2002) has obtained Sm-Nd ages of around 2.03 - 2.0 Ga on metamorphic minerals (whole rock – garnet isochrons) and, in the same area, a charnockitic body has been dated at 2.05 Ga by Pb-evaporation on zircon (Avelar *et al*., 2001). In northern Amapá, close to the city of Calçoene, zircons from another charnockitic pluton have furnished a Pb-Pb age of 2.06 Ga (Lafon *et al*., 2001) indicating that the high-grade (high-temperature) event extended over a wide area in Amapá. Delor *et al.* (2001a) and Roever *et al.* (2003) published similar ages (2.05 –2.07 Ga) for granulite in the northeastern part of Suriname. Metamorphic parageneses in the dated rocks support the occurrence of a late Transamazonian UHT episode related to late-orogenic continental-scale crustal extension in the southeastern Guiana Shield. Relationships between charnockitic magmatism and other granulitic rocks in the central Amapá sector are not constrained, and the existence of at least two high-grade episodes, one Archean and the other one Transamazonian in age, must not be discarded.

Conclusions

Our geochronological results (Pb-Pb evaporation on zircon and Sm-Nd on whole rock) for metasedimentary and meta-igneous units from Amapá State and southeastern French Guiana provide new evidence of the existence of Archean relics in the EGS. The relics, which occur as preserved reworked Archean nuclei in southern and central Amapá, extend up to the southeast of French Guiana where they are known only as detrital zircons in quartzite and as an inherited component in Paleoproterozoic paragneiss.

The Sm-Nd ages indicate a period of crustal growth between 3.29 and 2.92 Ga in central Amapá. In southeastern French Guiana, the 2.24-2.35 Ga model ages obtained for some granitoids indicate an early stage of crustal growth during the Transamazonian orogeny, while the 2.36-2.58 Ga model ages, provided by paragneiss and other granitoids, correspond to a mixture between a Proterozoic juvenile source and an Archean reworked source, rather than a Siderian (2.5-2.3 Ga) episode of crustal formation.

The Pb-Pb ages point to two magmatic episodes: one Mesoarchean at about 2.85 Ga and the other Neoarchean at about 2.58 Ga. The latter episode is, at the moment, poorly recognized throughout the whole of the Amazonian Craton.

The 2.77–3.19 Ga ages obtained on zircons from the quartzite, the 2.85 Ga age obtained on paragneiss from southeastern French Guiana, as well as the 2.85 Ga age obtained on tonalitic orthogneiss from central Amapá, indicate that Archean continental crust involved in the EGS underwent a similar Mesoarchean history as the Carajás Province. Strong evidence that a Neoarchean episode at *ca.* 2.58 Ga affected the southeasternmost part of the Guiana Shield comes from the Pb-evaporation ages obtained in this work and by Rosa Costa *et al.* (2001, 2003) and Ricci *et al.* (2001), whereas Neoarchean reactivation in the Carajás Province was restricted in intensity and limited to the northernmost sector (Carajás range). The Archean relics in the EGS may represent an extension of the Carajás Archean crust reactivated by a Neoarchean event and involved in the Transamazonian orogeny, but the lack of geochronological data over a distance of more than 500 km in a large domain between North Carajás and Amapá is a serious constraint to this assumption.

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