

Geology and geochronology of Archean and Paleoproterozoic domains of southwestern Amapá and northwestern Pará, Brazil, southeastern Guiana shield

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Géologie et géochronologie des domaines archéen et paléoprotérozoïque du sud-ouest de l'Amapá et du nord-ouest du Pará, Brésil, sud-est du Bouclier guyanais

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Key words: Archean, Lower Paleoproterozoic, Datation Pb-Pb, Tectonic domains, Brazil, Amapá, Pará, Guiana Shield.

Abstract

New geological mapping in the southeastern part of the Guiana Shield has provided a significant improvement in the geological knowledge of that area. New fieldwork, accompanied by geophysical map interpretation, petrography and Pb-Pb geochronology, has enabled the identification of dominant Archean and Paleoproterozoic domains separated by major tectonic boundaries. This paper presents the relevant geological data that constrain this tectonic partitioning, as well as the Pb-Pb geochronological data obtained from rocks acquired within different domains.

Résumé

Une nouvelle cartographie géologique réalisée dans la partie SE du Bouclier des Guyanes a permis d'améliorer significativement la connaissance géologique de cette région. De nouveaux travaux de terrain associés à l'interprétation de cartes géophysiques, d'études pétrographiques et géochronologiques par la méthode d'évaporation du Pb sur monozircon, ont conduit à identifier des domaines principalement d'âge archéen et paléoprotérozoïque, séparés par des limites tectoniques majeures. Cet article expose les données géologiques qui argumentent cette division tectonique ainsi que les données géochronologiques Pb-Pb acquises sur les roches de ces différents domaines.

Portuguese abridged version

A CPRM - Serviço Geológico do Brasil, através do Projeto Promin-RENCA, desenvolveu o mapeamento geológico em uma região de aproximadamente 33.000 km², localizada na fronteira dos estados do Pará e Amapá, sudeste do Escudo das Guianas, norte do Brasil (Fig. 1A).

A análise de informações de campo, interpretação de imagens aerogeofísicas e análises petrográficas permitiram o reconhecimento de diferentes domínios tectônicos na região, justapostos por grandes estruturas tectônicas, os quais foram individualizados por Ricci et al. (2001). Esta compartimentação tectônica é fundamentada em contrastes significativos em termos de conteúdo litológico dos complexos metamórficos de embasamento e unidades plutônicas, e em padrões geofísicos e estruturais. Neste trabalho, os referidos domínios são denominados, de NE para SW, de Domínio Cupixi (DC), Cinturão Jari (CJ) e Domínio Carecuru (DCR), e são balizados pelos lineamentos transcorrentes Cupixi e Ipitinga (Fig. 2A). Na tabela 1 são sumarizadas as características litológicas, estruturais e geocronológicas dos domínios tectônicos, e no mapa geológico da figura 2B é observada a distribuição espacial das unidades litológicas que compõem a geologia do Arqueano e Paleoproterozóico da região enfocada.

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Os domínios tectônicos apresentam uma direção NW-SE de estruturação dúctil, sendo que o CJ destaca-se como um domínio de maior concentração de deformação em relação aos adjacentes, contendo abundantes lineamentos radargamétricos, que representam principalmente zonas de cisalhamento transcorrentes e, em menor proporção, zonas contracionais. Os mapas aeromagnéticos também refletem o distinto padrão estrutural dos domínios em megaescala, nos quais é registrado um número significativo de anomalias magnéticas lineares no CJ, que representam os lineamentos estruturais, contrastando com um padrão magnético mais calmo nos demais.

A foliação apresenta ângulos de mergulho moderados, principalmente para SW, e as lineações de estiramento mineral indicam movimentação oblíqua, com vergência para NNE (Fig. 3A). Este padrão é modificado ao longo das zonas de cisalhamento transcorrentes, onde a foliação milonítica adquire altos ângulos de mergulho, as lineações de estiramento são subhorizontais e importantes feições de transposição são observadas (Figs. 3B, C e D).

A assembléia de embasamento do DC é representada principalmente por gnaisses TTG de fácies anfibolito, enquanto no CJ dominam rochas de alto grau metamórfico, representadas por ortognaisses granulíticos (Fig. 4A), rochas metassedimentares granulitizadas, ortognaisses granulíticos da transição anfibolito-granulito, além de gnaisses TTG e núcleos migmatíticos (Figs. 4B e C). No DCR o embasamento é representado essencialmente por gnaisses TTG (Fig. 4D) e em seu interior é reconhecido um núcleo granulítico, denominado Núcleo Granulítico Paru (NGP), constituído por ortognaisses granulíticos, hospedeiros de corpos charnockíticos intrusivos (Figs. 4E e F).

Datações realizadas neste trabalho, combinadas com dados previamente publicados, indicam padrões de idades predominantemente arqueanas para o CJ, DC e NGP, e predominantemente paleoproterozóicas para o DCR (Tabelas 1 e 2, Figs. 2B e 5).

As idades Pb-Pb arqueanas de 2652 ± 4 Ma e $\geq 2,80$ Ga, obtidas em zircões de gnaisses TTG e gnaisses enderbítico do CJ, respectivamente, indicam a atuação de dois eventos magmáticos no Neo e Mesoarqueano. As idades modelo Sm-Nd entre 3,06 – 3,1 Ga disponíveis para este domínio, indicam um episódio de crescimento crustal mesoarqueano (Sato e Tassinari, 1997).

No DC, idades Pb-Pb de 2,85 Ga e $\geq 2,58$ Ga obtidas em zircões de gnaisses TTG e granulíticos, respectivamente, bem como as idades modelo Sm-Nd entre 2,92 Ga e 3,36 Ga (Pimentel et al., 2002, Avelar et al., este volume), indicam um evento de acreção crustal na transição Paleo-Mesoarqueano e datam dois eventos magmáticos, aproximadamente contemporâneos àqueles identificados no CJ.

Ao contrário dos domínios adjacentes, ainda não foram registradas idades arqueanas no DCR. Um gnaiss TTG forneceu uma idade Pb-Pb em zircões de 2150 ± 1 Ma. No entanto, no NGP, foi obtida a idade Pb-Pb de 2597 ± 4 Ma em zircões de gnaiss enderbítico. Esta idade, somada às características estruturais e geofísicas fortemente contrastantes em relação às áreas adjacentes, permite considerar o NGP como um inlier arqueano no DCR.

Marcando a atuação da Orogenia Transamazônica na região, um importante evento magmático orogênico foi caracterizado, que promoveu a consolidação do DCR e o retrabalhamento dos domínios arqueanos. No CJ uma idade Pb-Pb de 2146 ± 3 Ma foi obtida em zircões de um álcali feldspato-granito. No DCR este magmatismo paleoproterozóico está representado pelas idades de 2150 ± 1 Ma e 2140 ± 1 Ma, obtidas em zircões de um gnaiss TTG e de um diorito, respectivamente. No NGP, um corpo charnockítico intrusivo nos gnaisses granulíticos arqueanos, forneceu uma idade Pb-Pb em zircão paleoproterozóica, mesmo não tendo sido bem limitada, provavelmente relacionada ao magmatismo transamazônico.

Os dados geocronológicos obtidos neste estudo e em trabalhos anteriores permitem caracterizar um segmento crustal arqueano que se estende a partir do Lineamento Ipitinga até a região central do Amapá, intensamente retrabalhado durante a Orogenia Transamazônica. Este segmento resulta de episódio de acreção crustal na transição Paleo-Mesoarqueano e eventos magmáticos durante o Meso e Neoarqueano. As idades paleoproterozóicas obtidas no DCR sugerem que domínios similares podem existir entre a região arqueana de Carajás, sudeste do Pará, e o segmento arqueano tratado neste estudo.

Introduction

The Geological Survey of Brazil-CPRM is involved in a 1:250,000- and 1:100,000-scale geological mapping program (Promin-RENCA Project) of approximately 33,000 km² in the southeast of the Guiana Shield, at the border between Pará and Amapá states of northern Brazil (Fig. 1A). The area is covered by dense equatorial forest, and a thick lateritic profile is developed over the Precambrian substratum. It is these physiographic characteristics that have hindered geological research in the area since the last geological work at the beginning of the 1980s, thus making it one of the geologically least known sectors of Brazil.

The new geological research, initiated in 2000, includes high-resolution airborne geophysics (magnetic and radiometric), coupled with remotely sensed imagery (Landsat TM5 and Jers 1), fieldwork, petrography, geochronological study and lithochemical analysis. Results from the current

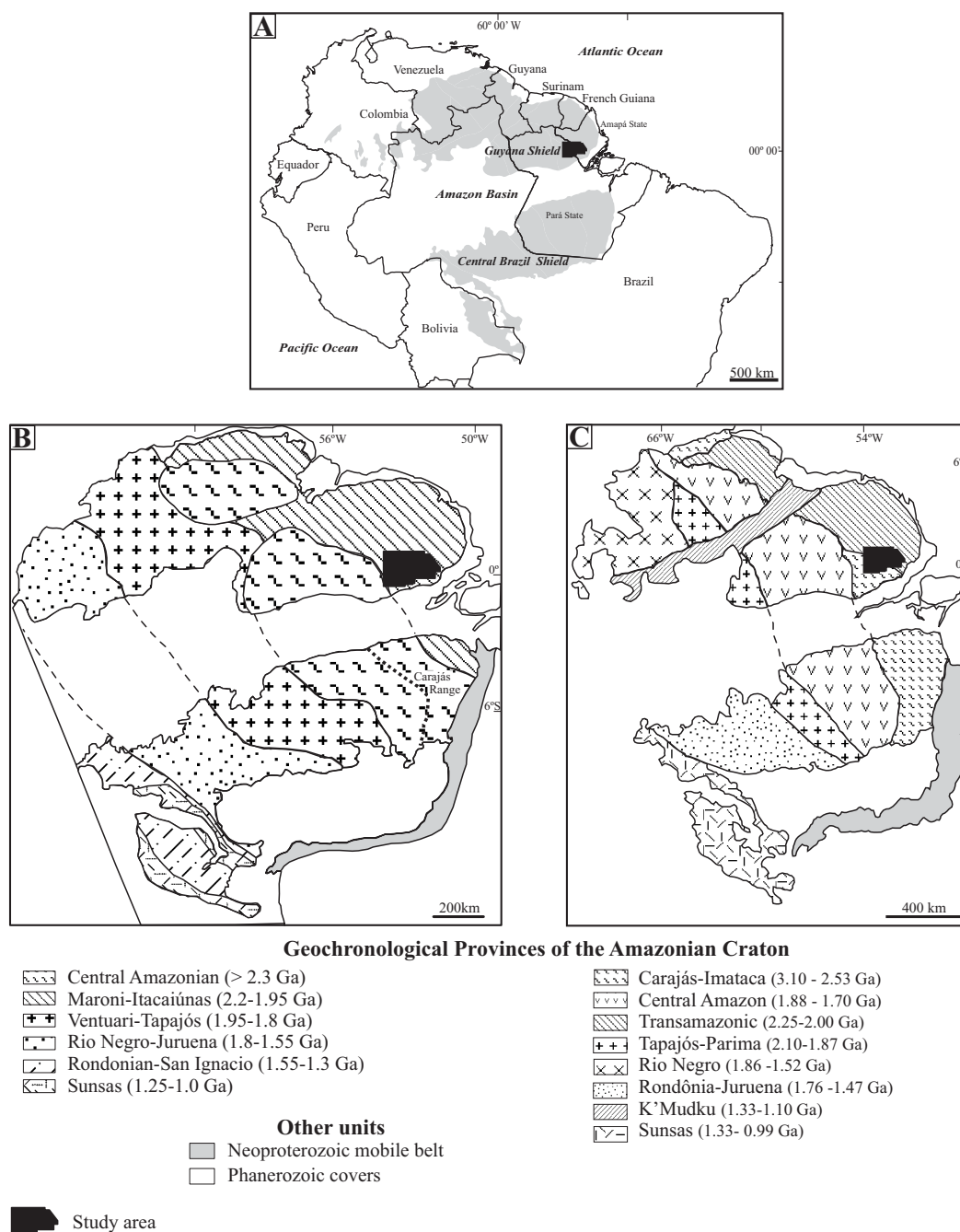


Fig. 1.- Sketch map of the Amazonian Craton, showing the location of the study area in the southeastern part of the Guiana Shield (A). Distribution of the Geochronological Provinces of the Amazonian Craton, based on proposals of (B) Tassinari *et al.* (2000) and (C) Santos *et al.* (2000).

Fig. 1.- Carte schématique du craton amazonien montrant la localisation du secteur étudié dans la partie sud-est du Bouclier guyanais (A). Répartition des provinces géochronologiques du Craton amazonien selon les propositions de (B) Tassinari *et al.* (2000) et (C) Santos *et al.* (2000).

stage of the work program, consisting fundamentally of field information (lithological and structural), petrographic results and Pb-Pb geochronological analyses (single zircon dating), have already enabled significant progress in the geological understanding of the area.

One of the most important contributions to understanding the geology of the area was the recognition

of dominant Archean and Paleoproterozoic terranes juxtaposed through tectonic contacts (Ricci *et al.*, 2001). According to these authors, significant contrasts in terms of lithological content and metamorphism of the basement complexes, as well as the distinct geophysical signatures and structural styles of the terranes, support this proposal of tectonic partitioning.

The purpose of the present paper is to present the relevant set of information acquired by the Promin-RENCA Project that led to the tectonic partitioning of Ricci *et al.* (2001). The main lithostratigraphic and structural aspects of the terranes are discussed, as well as the Pb-Pb geochronological data obtained from the basement and intrusive rocks of the different terranes.

Regional geological setting

The investigated area is located in the northeast of the Amazonian Craton, one of the largest cratonic areas of the world. This craton is divided into two Precambrian shields, namely the Guiana Shield in the north and the Brazil Central Shield in the south, separated by the Paleozoic Amazon Sedimentary Basin (Fig. 1A).

Tassinari *et al.* (2000), mainly on the basis of age determinations, divided the craton into six major geochronological provinces (Fig. 1B) that are in agreement with proposals established in previous work (Cordani *et al.*, 1979; Teixeira *et al.*, 1989; Tassinari, 1996; Tassinari and Macambira 1999). The studied area is located in the Maroni-Itacaiúnas Province (2.2 - 1.95 Ga), a widespread domain extending over the eastern part of the Guiana Shield and strongly marked by Transamazonian Orogeny (2.2 - 1.9 Ga). It consists of large areas of Paleoproterozoic crust incorporating Archean remnants that show a strong Paleoproterozoic metamorphic overprint. The Province is limited to the south and west by the Central Amazonian Province (>2.3 Ga), which is the oldest continental crust of the Amazonian Craton to be unaffected by the Transamazonian Orogeny.

Tassinari (1996) divided the Maroni-Itacaiúnas Province into two domains, named “simatic” and “ensialic”. The simatic domain, which extends from the French Guianas, across over Suriname, Guyana and the eastern part of Venezuela, was developed by juvenile crustal accretion during the Paleoproterozoic. Geochronological studies over the past two decades have confirmed that the main evolution of this domain occurred during the Paleoproterozoic (Gibbs and Olszewski 1982; Teixeira *et al.*, 1984, 1985; Gruau *et al.*, 1985; Egal *et al.*, 1994; Milési *et al.*, 1995; Vanderhaeghe *et al.*, 1998; Delor *et al.*, 1998, 2001a,b; Nogueira *et al.*, 2000; Avelar *et al.*, 2001, 2002; Lafon *et al.*, 2002).

The ensialic domain is restricted to the southeastern part of Maroni-Itacaiúnas Province, in northeastern Brazil. It is composed of Archean nuclei that were reworked during the Transamazonian Orogeny, and were preserved as inliers within Paleoproterozoic crustal rocks. From the central part of Amapá State (Tartarugal-Cupixi region) up to the border of French Guiana, Archean ages (Jorge João and Marinho, 1982; Montalvão and Tassinari, 1984; Sato

and Tassinari, 1997; Lafon *et al.*, 1998, 2000; Avelar *et al.*, 2001; Avelar, 2002; Lafon and Avelar, 2002) strongly suggest the involvement of an Archean crust in the southeastern part of the Maroni-Itacaiúnas Province.

According to Avelar *et al.* (this volume), the northern part of Amapá State represents a transition zone between the ensialic and simatic domains.

According to Tassinari *et al.* (2000), another important register of Archean remnants in the Maroni-Itacaiúnas Province is the high-grade polymetamorphic rocks of the Imataca Complex (>3.0 Ga to 2.0 Ga) in Venezuela (Montgomery and Hurley 1978; Teixeira *et al.*, 1989; Tassinari *et al.*, 2001).

Santos *et al.* (2000) proposed some significant modifications to the division of the Amazonian Craton into geochronological provinces, mainly in the eastern portion (Fig. 1C). The extended the Archean crustal segment, renamed as Carajás Province (3.1 - 2.53 Ga), from the Carajás region up to the southeastern part of Amapá State, where the boundary with the Transamazonian Province (2.25 - 2.0 Ga) was established. The Transamazonian Province roughly corresponds to the Maroni-Itacaiúnas Province of Tassinari *et al.* (2000). However, the Imataca Complex in Venezuela was excluded from the Transamazonian Province and considered as an Archean province.

Synthesis of current geological knowledge

Tectonic Domains

Ricci *et al.* (2001) demonstrated the presence of three tectonostratigraphic terranes in the area, referred as the Cupixi-Tartarugal Grande Ancient Terrane, the Jari Belt and the Carecuru-Paru Orogen. All present a dominant NE-SW structural trend and are bounded by first-order strike-slip zones, named the Cupixi Lineament and Ipitanga Lineament.

The concept of “tectonostratigraphic terrane”, adopted by Ricci *et al.* (2001), is based on definitions of Jones *et al.* (1986) and Howell (1995), who define a tectonostratigraphic terrane as “a fault-bounded package of rock with a distinct stratigraphy that characterizes a particular geologic setting, with a geological history different from the contiguous terranes”. This methodology of terrane analysis has been widely applied in other cratonic areas of the world (e.g. Coney *et al.*, 1980; De Wit *et al.*, 1992; Baars and De Wit, 1993; Dickin and Guo, 2001; Friend and Nutman, 2001; Zhao *et al.*, 2001).

In this paper, the tectonostratigraphic terranes identified by Ricci *et al.* (2001) are considered simply as tectonic domains, and have been renamed as the Cupixi Domain

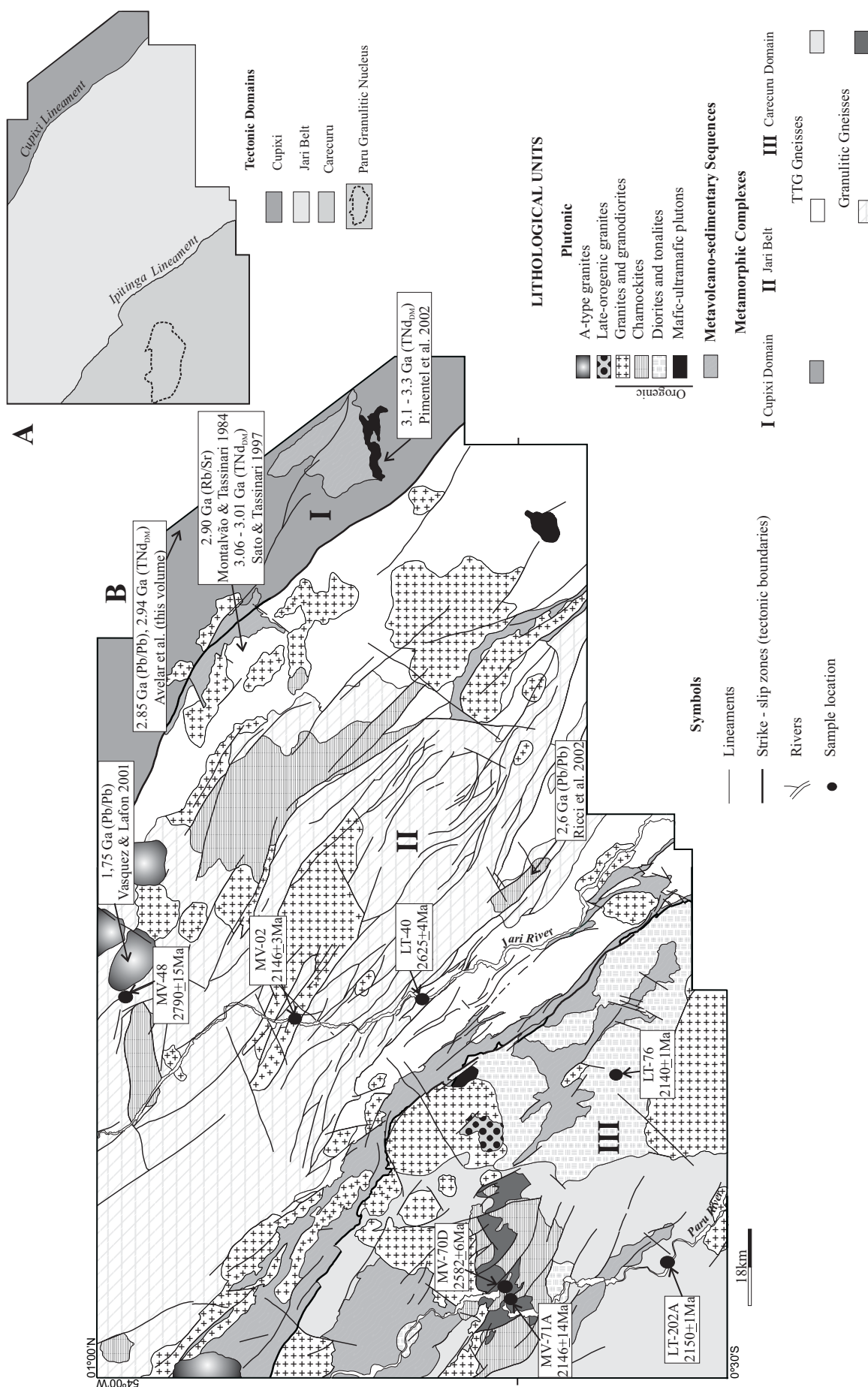


Fig. 2.- A: Tectonic domains of the study area. B: Geological map showing locations of samples dated in this work and in previous papers. Modified after Carvalho *et al.* (2001).

Fig. 2.- A : Domaines tectoniques de la zone étudiée. B : carte géologique montrant la localisation des échantillons datés dans cette étude ou dans des articles antérieurs. Selon Carvalho *et al.* (2001).

Tectonic domain	Basement rocks	Metamorphism	Plutonism	Structural and aerogeophysical patterns	Pb-Pb, Sm-Nd (TDM) and <u>Rb-Sr</u> ages ^a
Cupixi Domain	TTG gneiss	Amphibolite-facies, weak retrogression to greenschist facies, $\pm$ migmatization	Granite restricted to the limit with Jari Belt (within the studied area)	Minor map-scale lineaments and poorly disturbed magnetic pattern	2845 $\pm$ 6 Ma - TTG gneiss (protolith age) ¹ <i>2.94 – 3.36 Ga</i> – gneiss (crustal residence age) ^{1,2}
Jari Belt	TTG gneiss, migmatitic nuclei, granulitic orthogneiss, granulitic metasedimentary rocks	Amphibolite to granulite-facies, extensive retrogression to greenschist facies, strong migmatization	Charnokite, <i>sensu lato</i> granite, besides peraluminous granite and alkali-feldspar granite	Extensive deformation. Plutons occurring in sheets or lenses. Abundant map-scale lineaments (thrust and strike-slip zones). Strongly disturbed magnetic pattern	≥ 2.8 Ga - enderbitic gneiss (protolith age)* 2652 $\pm$ 4 Ma - TTG gneiss (protolith age)* 2605 $\pm$ 6 Ma – charnockite (crystallization age) ³ 2146 $\pm$ 3 Ma – alkali-feldspar granite (crystallization age)* <u>2.90 Ga</u> – tonalitic rocks (crystallization age) ⁴ <i>3.06 – 3.1 Ga</i> – tonalitic rocks (crustal residence age) ⁵
Carecuru Domain	TTG gneiss	Amphibolite-facies, $\pm$ migmatization	Dioritic to granodioritic rocks dominating, besides granite	Minor map-scale lineaments and poorly-disturbed magnetic pattern	2150 $\pm$ 1 Ma - tonalitic gneiss (protolith age)* 2140 $\pm$ 1 Ma – diorite- (crystallization age)*
Paru Granulitic Nucleus	Granulitic orthogneiss	Granulite-facies, weak migmatization	Charnokite	Curved map-scale lineaments. Distinctive magnetic pattern	2597 $\pm$ 4 Ma - enderbitic gneiss (protolith age)* Paleoproterozoic charnockites (2.06 – 2.16 Ga)*

^a **Bold:** Pb-Pb on zircon age; *italic:* Sm-Nd age on whole rock (TDM); underlined: Rb-Sr on whole rock. ¹Avelar *et al.* (this volume), ²Pimentel *et al.* (2002), ³Ricci *et al.* (2002),

⁴Montalvão and Tassinari (1984), ⁵Sato and Tassinari (1997), *this work

Table 1.- Main lithological units, structural and aerogeophysical patterns and available ages in each tectonic domain of the study area.

Tabl. 1.- Unités lithologiques principales, caractéristiques structurales et aérogéophysiques et âges disponibles pour chacun des domaines tectoniques de la zone étudiée.

(CD), Jari Belt (JB) and Carecuru Domain (CRD), respectively from northeast to southeast (Fig. 2A). These tectonic domains show clear contrasts in terms of lithological content, age and metamorphic grade of the basement metamorphic complexes, as well as strong differences related to structural style and geophysical signature. Rosa-Costa *et al.* (2002a) describe the principal geophysical signatures that characterize the three tectonic domains. The main geological characteristics of the domains are summarized in Table 1 and a geological map of the studied area is presented in Figure 2B.

The CD is dominated by Mesoarchean TTG gneiss that is affected by amphibolite-facies metamorphism and shows a NW-SE foliation (compositional banding) dipping at a medium angle to both NE and SW. The number of map-scale lineaments is comparatively smaller than in the adjacent JB domain, resulting in a poorly disturbed magnetic pattern.

The JB is a linear belt, approximately 100 km wide, whose basement assemblage is dominated by rocks of high metamorphic grade -mainly Mesoarchean and Neoproterozoic orthogneiss metamorphosed from granulite facies to the amphibolite-granulite transition facies, and affected by retrograde greenschist metamorphism. The belt is

characterized by a conspicuous NW-SE ductile structuring, highlighted in satellite images by a significant number of map-scale lineaments and in aeromagnetic maps by a large incidence of high frequency linear anomalies. These lineaments mainly represent strike-slip zones superimposed on the earlier thrust zones, and control the shape of the granitoid plutons that are exposed as elongate strips and ellipsoidal and sigmoidal lenses, aligned along the regional trend.

The rocks within the JB show a pervasive foliation systematically dipping 20-60° SW. The stretching lineation indicates the oblique NNE-trending movement (Fig. 3A). This pattern is strongly disturbed along the NW-SE strike-slip zones, where steeply dipping foliation and subhorizontal stretching lineation are registered. Kinematic approaches (S-C structures and rotated porphyroclasts) point to a dextral movement, though a significant number of sinistral zones with the same trend have also been observed.

Major strike-slip zones (the Ipitinga and Cupixi lineaments) stand out in aeromagnetic maps as continuous linear anomalies separating the JB from the adjacent domains. Steep mylonitic foliation and subhorizontal

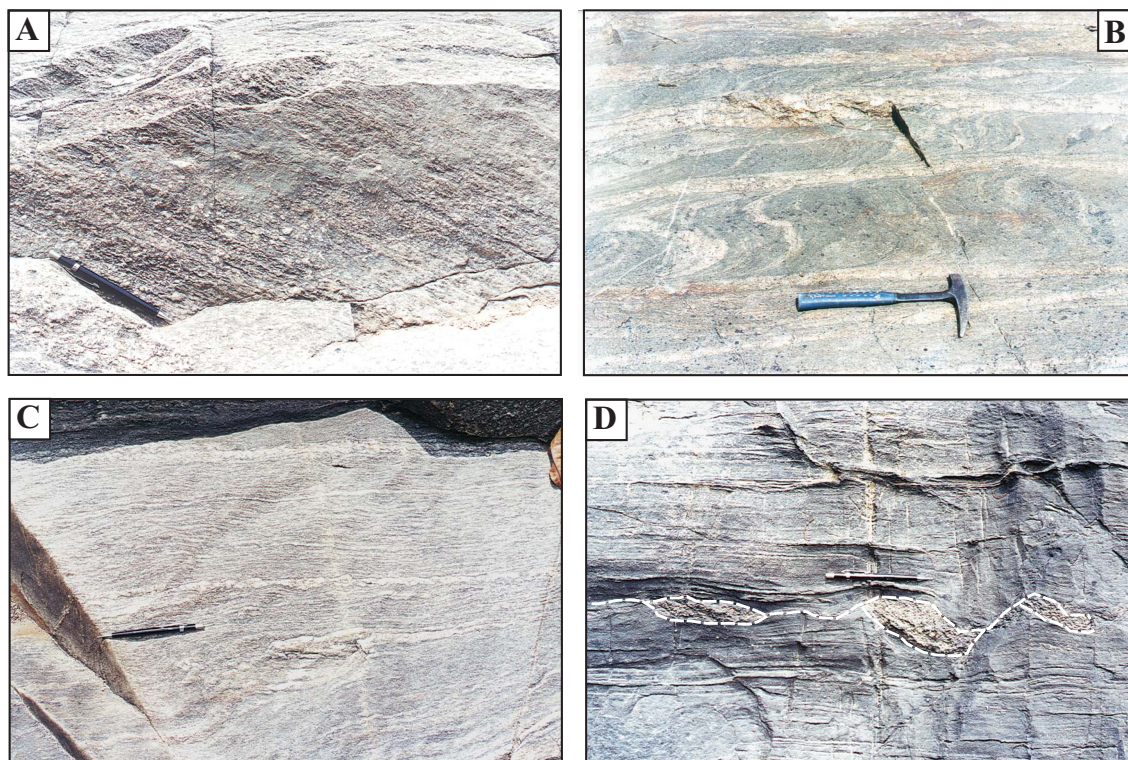


Fig. 3.- Structural features observed in the Jari Belt (A) and along the Ipitinga Lineament (B, C and D). A: Stretching lineation defined by rodding of quartz and feldspar. B: Transposition of the gneissic banding through dextral strike-slip bands, developing S/C -type structures. C: High-strain mylonitic fabric developed in the orthogneiss displayed in B. D: Rotated and boudinaged quartz vein (outlined) hosted in mafic schist.

Fig. 3.- Caractéristiques structurales observées dans la ceinture du Jari (A) et le long du linéament Ipitinga (B, C et D). A : Linéation d'étirement définie par le quartz et le feldspath. B : Transposition des lits gneissiques suivant des bandes de décrochement dextres, qui développe des structures de type S/C. C : Fabrique mylonitique high strain dans le même orthogneiss que B. D : Veine de quartz pivotée et boudinée (soulignée) dans un « schiste » basique.

stretching lineation are registered within these shear zones. Moreover, structural features that indicate reworking of pre-existing fabrics can be recognized as banding transposed in S-C structures; it progresses into parallel fabric (Figs. 3B and C) and boudinage veins (Fig. 3D). Similar structural features have been described in tectonic boundaries of crustal blocks in other areas (Passchier, 1994; Gibbons *et al.*, 1996; Webster *et al.*, 1998; St-Onge *et al.*, 2001).

Due to the scarcity of decisive kinematic indicators, the movement along these structures has not yet been confidently determined, although most of the data points to a sinistral component in the Cupixi Lineament and a dextral component in the Ipitinga Lineament. Down-dip stretching lineation is locally observed along the Ipitinga Lineament, suggesting an earlier reverse movement.

The regional basement of the CRD consists of Paleoproterozoic amphibolite-facies TTG gneiss intruded by a profusion of orogenic plutons. The plutons display heterogeneous internal structural patterns and include

rocks whose texture ranges from a preserved granular igneous texture to mylonitic foliation.

The NW-SE trend is marked in this domain, where foliation dips 50-60° SW and stretching lineation indicates a NNE-verging sense of displacement. This pattern can be modified along strike-slip zones, where steeply dipping mylonitic foliation is registered. Map-scale lineaments are not as abundant as in the JB. The heterogeneous structural pattern of the CRD can be recognized on first-derivative magnetic maps. Sections presenting typical poorly disturbed magnetic pattern alternate with others showing abundant linear magnetic anomalies that correspond to mylonitic zones.

The Paru Granulitic Nucleus (PGN) that has been individualized within the CRD is composed mainly of Neoproterozoic granulitic orthogneiss and intrusive Paleoproterozoic charnockite. A curvilinear pattern of the major lineaments has been registered within this nucleus from both magnetic and remotely sensed images. This pattern characterizes a distinct structural style in relation to the adjacent areas within the CRD.

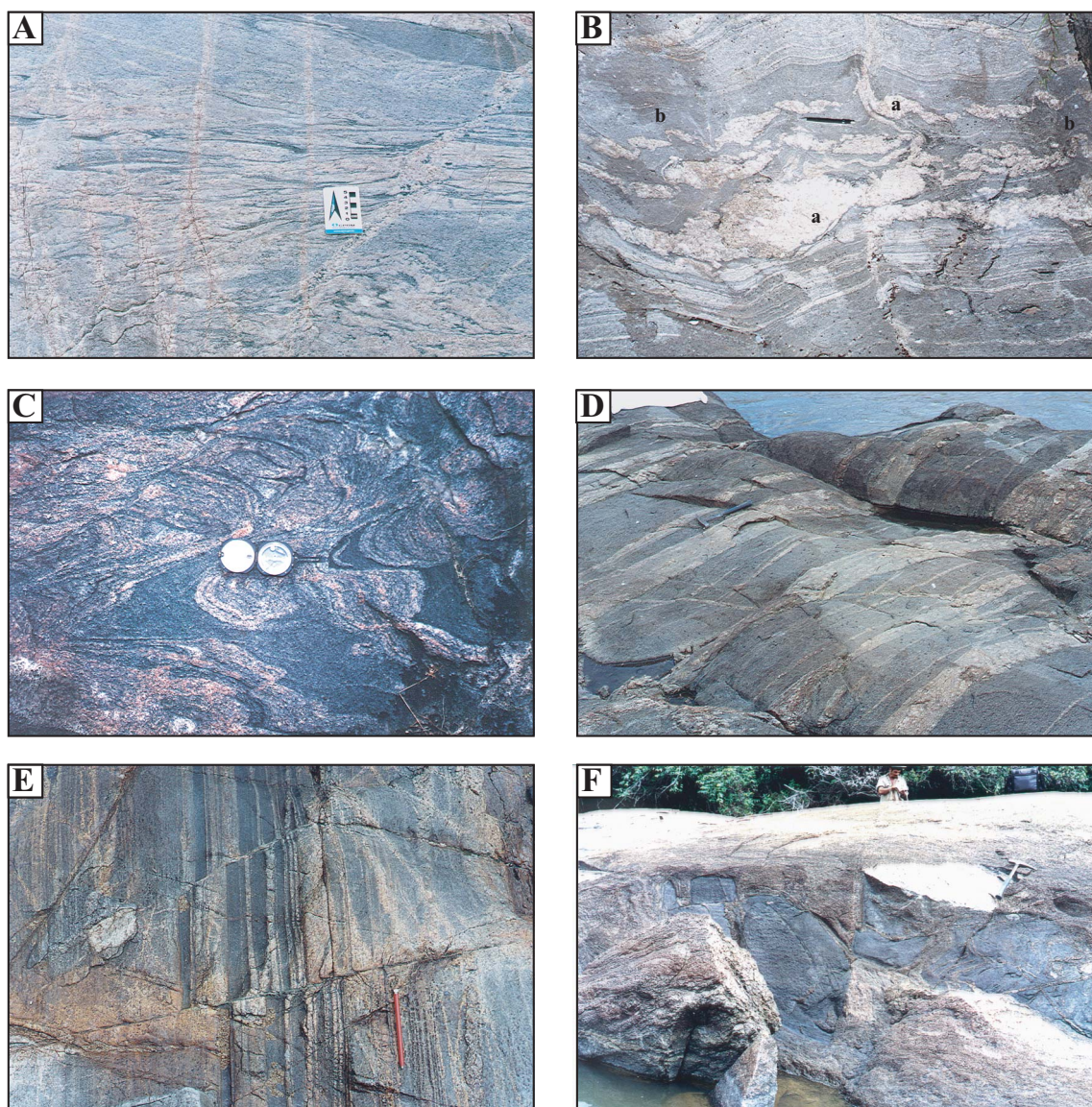


Fig. 4.- Field aspects of the orthogneiss and charnockite. A: Migmatized granulitic gneiss. B: Orthogneiss exhibiting a higher stage of migmatization, where granitic leucosomes (a, pale coloured) and dioritic melanosomes (b, dark coloured) can be recognized. C: Granitic migmatite showing a convergent-divergent pattern of folding. Features A, B and C were registered in the Jari Belt. D: Tonalitic gneiss of the Carecuru Domain hosting granitic veins parallel to the foliation. E: Centimetre-scale banding observed in orthogneiss of the Paru Granulitic Nucleus, defined by alternating layers of enderbitic granulite and mafic granulite. F: Xenoliths of granulitic gneiss inside the charnockitic body of the Paru Granulitic Nucleus.

Fig. 4.- Aspects de terrain des orthogneiss et charnockites. A : gneiss granulitique migmatisé. B : orthogneiss présentant un plus haut degré de migmatisation, dans lequel on reconnaît des leucosomes granitiques (a, en clair) et des mélanosomes dioritiques (b, en sombre). C : migmatite de composition granitique montrant des plissements convergents-divergents. Les photos A, B et C proviennent de la ceinture du Jari. D: Gneiss tonalitique du domaine Carecuru contenant des veines granitiques parallèles à la foliation. E : Litage d'échelle centimétrique dans une granulite orthodérivée du noyau granulitique Paru, montrant une alternance de lits de granulites enderbitiques et de lits de granulites basiques. F : Xenoliths de gneiss granulitiques dans un corps charnockitique du noyau granulitique Paru.

Lithological units

The tectonostratigraphic units are joined in three major lithological groups that represent the Archean and Paleoproterozoic geology of the area (Fig. 2B).

Basement metamorphic complexes

The CD basement is composed of banded amphibolite-facies TTG gneiss that shows alternating centimetre-thick layers of granodioritic-granitic, trondhjemitic-granitic or tonalitic-quartz dioritic composition. It is moderately migmatized.

The JB basement is dominated by high-grade ortho-derived and paraderived metamorphosed rocks, as well as amphibolitic TTG gneiss. The orthoderived rocks are represented by enderbitic and charnoenderbitic gneiss that contains centimetre-scale lenses of mafic granulite. Granitic gneiss metamorphosed to amphibolite-granulite transition facies (mesoperthite and clinopyroxene-bearing gneiss), locally reaches granulite grade (charnockitic orthogneiss), and was also registered within the orthoderived group. It is strongly migmatized (Fig. 4A), complexly deformed, and shows common transposition structures, such as rootless intrafolial folds.

Granulitic metasedimentary rocks occur subordinately in narrow belts surrounded by orthogneiss, represented mainly by quartzite with garnet and sillimanite, kinzigite with cordierite, BIF with clinopyroxene, and garnet-biotite-sillimanite-quartz schist.

Amphibolite-facies TTG gneiss is included in the basement assemblage of the JB. The intensity of migmatization varies from weak to strong (Fig. 4B). Kilometre-scale nuclei composed of sodic and potassic migmatite has been mapped within this domain. They are structurally complex and commonly exhibit an interference pattern of folding (Fig. 4C) that can be characterized as the convergent-divergent type of Ramsay and Huber (1987). Migmatitic nuclei were not found in the other domains.

The basement of the CRD is defined by banded amphibolite-facies TTG gneiss. It is weakly to moderately migmatized and exhibits meter-thick injections of granitic composition (Fig. 4D), as well as mafic bodies such as irregular sheets and dikes that show a foliation parallel to banding of the hosting gneiss. Banded granulitic orthogneiss has been distinguished within the Paru Granulitic Nucleus of the CRD. This orthogneiss has alternate centimetre-scale layers composed of enderbite/charnoenderbite and mafic granulite. In contrast to the granulitic gneiss of the JB, it is weakly migmatized (Fig. 4E). Isotropic bodies of mafic granulite, without migmatization, are also included in this nucleus.

Metavolcano-sedimentary sequences

The metavolcano-sedimentary sequences are generally located at the boundaries between the domains, where they are structurally controlled by strike-slip zones; they also occur as dismembered strips within the domains (Fig. 2B). The former comprise rocks of volcanic and sedimentary (chemical-exhalative and clastic) origin, and the latter are mainly of volcanic origin.

The dominant lithotypes of the metavolcanics are mafic and ultramafic schist and ultramafic subvolcanic bodies (metadunite and metapyroxenite). Banded iron formations (BIF) are found in the intermediate part of the sequence, which is dominated by oxide-facies, although silicate-facies have also been found. The clastic metasedimentary portion is represented by orthoquartzite, ferruginous and aluminous quartzite, and pelitic and psammitic mica schist.

These sequences are metamorphosed in greenschist to amphibolite facies and show a steep penetrative foliation (schistosity, mylonitic and ultramylonitic foliation). Folds are commonly observed in the BIF, indicating their plastic behaviour to the deformation. Isotropic rocks are also observed, associated mainly with the intradomain sequences.

Metamafic rocks of the supracrustal belt controlled by the Ipitanga Lineament produced Sm-Nd ages between 2.26 and 2.19 Ga (Faraco, 1997; McReath and Faraco, 1997). These ages are in agreement with other Sm-Nd and U-Pb ages obtained from supracrustal sequences of the northern portion of Guiana Shield (Gibbs and Olszewski, 1982; Gruau *et al.*, 1985; Norcross *et al.*, 2000) and correlate these sequences to the Transamazonian Orogeny.

Plutonic units

Several intrusive suites and magmatic bodies are described by Ricci *et al.* (in press) to characterize the Paleoproterozoic orogenic, late-orogenic and anorogenic magmatism of the area.

The orogenic plutons, because of their well-developed anisotropic fabric, were previously considered as part of the basement metamorphic assemblage. They present a wide compositional spectrum, varying from the less-evolved quartz-diorite, diorite and tonalite to more-evolved granite with minor granodiorite.

The less-evolved granitoids are restricted to the CRD where they are structurally heterogeneous. Preserved igneous textures (equigranular and porphyritic) and mylonitic foliation can be found within a same pluton.

Granite and granodiorite are present in all the domains, as well as along their tectonic boundaries. The plutons within the CRD display an irregular shape, whereas within the JB they are elongate according to the NW-SE regional trend and are commonly mylonitized.

A catazonal orogenic magmatism, represented by several charnockitic plutons hosted by granulite-facies orthogneiss is identified within the JB and PGN. In addition to charnockite, the plutons contain charnoenderbite and alkali-feldspar granite with mesoperthite and antiperthite plagioclase.

In the PGN the plutons exhibit an irregular shape and it is common to observe magma flux foliation (orientation of tabular alkali feldspar) parallel to the mylonitic foliation. In the JB, the plutons occur as kilometre-scale lenses and sigmoids that are oriented along-trend, and the rocks generally exhibit mylonitic foliation. Granulitic gneiss xenoliths (Fig. 4F) are registered within these rocks.

Small mafic-ultramafic bodies are seen locally in the CRD and JB, and an interlayered mafic-ultramafic intrusion within the CD (Sá *et al.*, 1996; Spier, 1999) has been dated at ca. 2.2 Ga (Sm-Nd isochron, Pimentel *et al.*, 2002).

The late-orogenic magmatism is represented by undated isotropic monzogranitic to tonalitic plutons. Nevertheless, Rosa-Costa *et al.* (2002b) dated a 2050 ± 2 Ma (Pb-Pb single zircon) felsic metavolcanic rock, which suggests an age for this magmatic event. The anorogenic magmatism is marked by 1753 ± 3 Ma A-type granite (Pb-Pb single zircon, Vasquez and Lafon, 2001).

Geochronological study

Sampling

Pb evaporation dating was performed during this study on three samples from the JB and four samples from the CRD. The three samples from the JB correspond to an enderbitic orthogneiss (sample MV-48) and TTG gneiss (sample LT-40) and an alkali-feldspar granite (sample MV-02). The four samples from the CRD correspond to a TTG gneiss (sample LT-202A), a diorite (sample LT-76), an enderbitic orthogneiss from the PGN (sample MV-70D) and an intrusive charnockite from the PGN (sample MV-71A) -sample locations are shown in Figure 2B.

The samples were taken away from veins, tectonic structures and lithological contacts in order to prevent contamination. Homogeneous gneiss was collected with great care to avoid areas with migmatitic segregation. Petrographic descriptions of the dated samples are given in Appendix A.

Experimental Procedures

Zircon crystals from orthogneiss and granitoid of the investigated area were analysed by the single-grain Pb evaporation method (Kober, 1986, 1987) at the geochronological laboratory of the Universidade Federal do Pará (Pará-Iso), Belém, Brazil. Sample preparation and zircon concentration were done at the CPRM laboratories. Two granulometric fractions were separated (150-200 mesh and 80-150 mesh). The dated zircons were preferentially selected within the 80-150 mesh fraction. The Pb isotope compositions were determined through repeated analyses of several zircon grains at increasing temperature steps on a Finnigan MAT262 mass spectrometer in dynamic mode using an ion counting detector. The $^{207}\text{Pb}/^{206}\text{Pb}$ ratios were corrected by a mass discrimination factor of $0.12\% \pm 0.03$ per u.m.a. determined by repeated analyses of an NBS-982 “equal atoms” Pb standard. The calculation of common lead correction was done using the Stacey and Kramers (1975) model. Analyses with $^{206}\text{Pb}/^{204}\text{Pb}$ ratios lower than 2500 were eliminated to minimize the effects of common-lead correction and are not shown in the table of isotopic data.

The Pb evaporation method usually provides very precise measurements of the $^{207}\text{Pb}/^{206}\text{Pb}$ ratio, which

enable the determination of a precise weighted average value for the age ($\pm 1-5$ Ma) on a small number of grains. As Pb/U ratios are not determined, the $^{207}\text{Pb}/^{206}\text{Pb}$ age is a minimum age. However, the assumption that they can represent a “concordant” crystallization age of zircon from magmatic rocks is strongly supported when repeated measurements of $^{207}\text{Pb}/^{206}\text{Pb}$ do not vary in different crystals or at different temperature steps in one grain (Kober *et al.*, 1989; Ansdell and Kyser, 1993; Karabinos and Gromet, 1993; Kröner *et al.*, 1999).

The age of each sample is obtained using the mean of the $^{207}\text{Pb}/^{206}\text{Pb}$ ratios at the highest temperature step of at least 4 crystals, when possible. When different temperature steps of the same grain give similar ages, all are included in the mean calculation of the age of that grain. Grains furnishing lower ages are suspected of having suffered lead loss after crystallization and are discarded. Therefore, only zircons with the higher ages are considered as having preserved their lead and as being appropriate for mean age determination. The weighted mean and the errors on the ages were calculated following Gaudette *et al.* (1998). The age spectra were elaborated using the Isoplot program of Ludwig (2000).

Isotopic Results

The analytical results are presented in Table 2 at the 2-sigma level.

Results obtained in rocks from the Jari Belt

Isotopic analyses for the JB were made on 8 zircon grains from the enderbitic gneiss, 10 zircon grains from the granodioritic gneiss, and 10 zircon grains from the alkali-feldspar granite.

The eight grains from the enderbitic gneiss (sample MV-48) gave $^{207}\text{Pb}/^{206}\text{Pb}$ ages spread between 2370 Ma and 2797 Ma. The high temperature steps of the older grain furnished an age of 2797 ± 3 Ma that is considered as a minimum age for the crystallization of the zircons in the magmatic protolith. As no Rhyacian ages were found in the studied zircon population, the variations in the ages are assumed to represent the influence of the Transamazonian metamorphism and deformation on the U-Pb system of the zircon, rather than variable amounts of an inherited component in Paleoproterozoic (i.e. Transamazonian-related) zircons.

Of the 10 crystals analysed from the granodioritic gneiss (sample LT-40), nine yielded ages between 2641 Ma and 2667 Ma - grain #8 was excluded. The nine grains furnished a mean $^{207}\text{Pb}/^{206}\text{Pb}$ age of 2652 ± 4 Ma, which is interpreted as the crystallization age of the granodioritic protolith. Most of the grains gave at least two temperature

Zircon	T(°C) step	No. of ratios	$\frac{^{206}\text{Pb}}{^{204}\text{Pb}}$	$\frac{^{208}\text{Pb}}{^{204}\text{Pb}}$	2σ	$\frac{^{207}\text{Pb}^*}{^{206}\text{Pb}^*}$	2σ	Step age (Ma)	2σ (Ma)	zircon age (Ma)	2σ (Ma)
<i>Enderbitic gneiss (sample MV-48)</i>											
MV-48/1	1450	38	13699	0.09403	168	0.12817	66	2073	9		
	1503	90	18519	0.11909	365	0.15209	163	2370	18	2370	18
MV-48/2	1500	84	10753	0.10112	91	0.14822	57	2326	7		
	1550	86	20833	0.13352	34	0.17525	32	2609	3	2609	3
MV-48/3	1500	82	4695	0.27357	230	0.19471	36	2783	3	2783	3
MV-48/4	1500	82	11628	0.14468	65	0.17071	39	2565	4		
MV-48/5	1500	66	10204	0.22589	133	0.18986	52	2741	4	2741	4
	1550	18	4587	0.27784	154	0.18618	69	2709	6		
MV-48/6	1450	36	37037	0.15903	170	0.1887	91	2731	8		
	1500	64	166667	0.19645	387	0.19645	30	2797	3	2797	3
MV-48/7	1500	16	27027	0.13994	158	0.19131	105	2754	9	2754	9
	1450	50	6410	0.1539	247	0.18316	44	2682	4		
MV-48/8	1500	90	250000	0.20047	45	0.19317	23	2770	2	2770	2
	1550	16	> 1000000	0.19282	191	0.19066	99	2748	9		
<i>TTG gneiss (sample LTR-40)</i>											
LT-40/1	1450	16	19231	0.07352	262	0.18612	285	2708	25		
	1500	88	8929	0.11846	31	0.1803	40	2656	4	2656	4
LT-40/2	1460	52	11236	0.10538	61	0.18153	60	2667	5	2667	5
LT-40/3	1490	72	16667	0.09655	69	0.1793	92	2647	9	2647	9
LT-40/6	1500	38	27778	0.07957	44	0.17961	76	2650	7	2650	7
LT-40/8	1400	6	2538	0.10231	72	0.18246	54	2676	5		
	1450	40	16129	0.10254	76	0.18454	73	2695	7	2695	7
	1500	40	14706	0.15356	39	0.18303	28	2681	3		
LT-40/9	1490	88	9901	0.09428	22	0.18071	22	2660	2		
	1520	6	10101	0.10037	54	0.17978	79	2651	7	2659	4
LT-40/10	1470	84	6452	0.06448	17	0.17996	22	2653	2		
	1510	36	4608	0.0739	23	0.18026	36	2656	3	2654	2
LT-40/12	1500	84	14286	0.06378	16	0.18037	22	2657	2		
	1550	88	13333	0.07599	20	0.18027	24	2656	2	2656	1
LT-40/13	1490	90	10870	0.05859	88	0.17871	21	2641	2		
	1520	86	10870	0.06144	23	0.1787	28	2641	3	2641	2
LT-40/14	1500	84	43478	0.10372	98	0.18141	41	2666	4		
	1550	50	55556	0.13589	52	0.17872	45	2641	4	2641	4
Mean age (9 grains - 878 ratios - USD = 5.3)										2652	4
<i>Alkali feldspar granite (sample MV-02)</i>											
MV-02/1	1450	80	11905	0.13862	52	0.13138	21	2117	3		
	1506	40	76923	0.14311	38	0.13385	64	2149	8	2149	8
MV-02/2	1500	84	37037	0.11724	83	0.13229	21	2129	3		
	1550	28	26316	0.10311	36	0.13147	29	2118	4	2125	10
MV-02/3	1450	88	20408	0.11939	28	0.12819	18	2074	3		
	1500	54	41667	0.11875	84	0.12862	24	2079	3	2076	6
MV-02/4	1500	86	27027	0.15334	36	0.13366	17	2147	2	2147	2
MV-02/5	1500	86	3106	0.1536	156	0.12828	36	2075	5	2075	5
MV-02/6	1500	86	9804	0.205	49	0.13381	18	2149	2	2149	2
MV-02/7	1450	18	3704	0.11289	90	0.12836	64	2076	9		
	1500	88	30303	0.10356	25	0.12898	20	2084	3		
	1550	88	30303	0.10711	29	0.12852	40	2078	6		
	1580	16	90909	0.1105	64	0.12906	40	2085	5	2083	3
MV-02/8	1500	84	15873	0.10083	22	0.12887	15	2083	2		
	1550	18	11765	0.1094	58	0.1293	35	2089	5	2084	4
MV-02/9	1500	88	27778	0.18484	41	0.13297	16	2138	2		
	1550	88	40000	0.18435	42	0.1333	16	2142	2	2142	2
MV-02/10	1500	88	23810	0.13891	63	0.13215	20	2127	3	2127	3
Mean age (4 grains - 300 ratios - USD = 2.6)										2146	3

Table 2.- Isotopic results and Pb-Pb ages on zircons for the dated samples.

Tabl. 2.- Résultats isotopiques et âges Pb-Pb sur zircon pour les échantillons datés.

Zircon	T(°C) step	No. of ratios	$\frac{^{206}\text{Pb}}{^{204}\text{Pb}}$	$\frac{^{208}\text{Pb}}{^{204}\text{Pb}}$	2 σ	$\frac{^{207}\text{Pb}^*}{^{206}\text{Pb}^*}$	2 σ	Step age (Ma)	2 σ (Ma)	zircon age (Ma)	2 σ (Ma)
<i>TTG gneiss (sample LT-202A)</i>											
LT-202A/1	1450	36	13889	0.14961	113	0.13118	25	2114	3		
	1470	36	16393	0.15288	37	0.13245	42	2131	6	2131	6
LT-202A/3	1480	8	>1000000	0.1045	61	0.13308	60	2139	8	2139	8
LT-202A/5	1480	32	66667	0.12585	70	0.13194	50	2124	7	2124	7
LT-202A/6	1440	8	15625	0.13828	440	0.13283	165	2136	22		
	1460	18	90909	0.10603	90	0.13259	79	2133	10	2133	9
LT-202A/7	1500	90	12048	0.1211	27	0.13326	19	2142	3		
	1505	36	7576	0.11985	50	0.13311	34	2140	4		
	1550	90	19608	0.13763	35	0.13407	18	2152	2	2152	2
LT-202A/8	1480	18	22222	0.15515	78	0.13384	65	2149	8		
	1520	86	9901	0.17392	55	0.13381	16	2149	2	2149	2
LT-202A/9	1470	36	10000	0.12622	80	0.13425	78	2155	10		
	1540	8	>1000000	0.11912	90	0.13432	75	2155	10	2155	7
LT-202A/10	1450	8	14085	0.10953	89	0.13242	62	2131	8		
	1500	30	32258	0.10084	26	0.13386	19	2149	3		
	1530	34	6173	0.10833	134	0.1338	25	2149	3	2149	2
LT-202A/11	1500	82	23256	0.1035	29	0.13405	32	2152	4	2152	4
LT-202A/12	1500	54	28571	0.12397	80	0.13362	49	2146	6	2146	6
Mean age (6 grains - 438 ratios - USD = 1.1)										2150	1
<i>Diorite (sample LT-76)</i>											
LT-76A/1	1450	8	5236	0.11242	54	0.13218	47	2127	6		
	1500	22	166667	0.14971	151	0.13264	59	2134	8	2130	6
LT-76A/2	1480	28	9091	0.12771	255	0.13058	31	2106	4	2106	4
LT-76A/3	1450	18	15625	0.11623	200	0.13185	27	2123	4		
	1500	4	>1000000	0.13538	321	0.13258	37	2133	5	2126	9
LT-76A/4	1422	38	22222	0.13561	48	0.13288	21	2137	3		
	1451	16	>1000000	0.11163	66	0.1331	56	2139	7	2137	3
LT-76A/5	1450	8	10753	0.10221	134	0.13222	206	2128	27		
	1470	8	111111	0.11557	97	0.13304	155	2139	20	2135	16
LT-76A/7	1450	28	18182	0.11676	110	0.13277	30	2135	4		
	1471	30	142857	0.12847	31	0.13327	19	2142	2	2142	2
LT-76A/8	1440	24	16949	0.0862	52	0.13274	31	2135	4		
	1495	88	83333	0.09858	90	0.13342	20	2144	3		
	1550	18	29412	0.13679	96	0.13346	62	2144	8	2144	3
LT-76A/9	1450	38	13158	0.13904	32	0.13264	26	2134	3		
	1500	88	28571	0.13527	36	0.13324	32	2141	4		
	1520	8	71429	0.12528	79	0.13357	52	2146	7	2143	4
LT-76A/10	1450	36	200000	0.10477	43	0.13299	36	2138	5		
	1470	86	83333	0.13275	110	0.13324	23	2141	3		
	1500	86	1000000	0.15981	47	0.13309	19	2139	3	2140	2
LT-76A/11	1480	86	26316	0.14146	32	0.13324	18	2141	2		
	1500	82	40000	0.14819	34	0.13302	23	2138	3		
	1550	86	37037	0.14492	62	0.13282	24	2136	3	2139	3
LTR-76A/12	1500	86	27778	0.15705	59	0.13302	19	2138	2	2138	2
Mean age (6 grains - 780 ratios - USD = 1.8)										2140	1

Table 2.- Continued/Suite

Zircon	T(°C) step	No. of ratios	$\frac{^{206}\text{Pb}}{^{204}\text{Pb}}$	$\frac{^{208}\text{Pb}}{^{204}\text{Pb}}$	2 σ	$\frac{^{207}\text{Pb}^*}{^{204}\text{Pb}^*}$	2 σ	Step age (Ma)	2 σ (Ma)	zircon age (Ma)	2 σ (Ma)
Enderbitic Orthogneiss (sample MV-70D)											
MV-70D/1	1450	38	9901	0.05489	17	0.17232	21	2581	2		
	1500	82	7634	0.06099	16	0.17223	24	2580	2	2580	2
MV-70D/2	1450	88	10101	0.17702	365	0.15529	41	2405	5		
	1500	88	15873	0.1897	44	0.15929	30	2449	3		
	1550	88	27778	0.20587	142	0.16554	48	2513	5	2513	5
MV-70D/3	1500	28	31250	0.26423	169	0.1637	61	2495	6		
	1550	18	33333	0.26189	142	0.17007	68	2559	7	2559	7
MV-70D/4	1500	88	62500	0.15515	82	0.17075	20	2565	2	2565	2
	1550	88	166667	0.20562	74	0.16964	26	2554	3		
	1600	36	90909	0.24957	91	0.16776	39	2536	4		
MV-70D/5	1500	90	21739	0.10069	37	0.17234	28	2581	3	2581	3
MV-70D/6	1450	28	22222	0.14055	64	0.17288	68	2586	7		
	1500	90	50000	0.13718	173	0.17434	50	2600	5	2600	5
MV-70D/8	1500	88	16393	0.17572	41	0.17098	44	2568	4		
	1550	52	21277	0.23514	330	0.17392	32	2596	3	2596	3
MV-70D/9	1450	86	2653	0.0961	53	0.15894	32	2445	3		
	1500	88	15873	0.11626	47	0.1691	28	2549	3		
	1550	90	19608	0.14271	123	0.1727	25	2584	2	2584	2
Mean age (2 grains - 142 ratios - USD = 1.4)										2597	4
Igneous charnockite (sample MV-71A)											
MV-71A/1	1500	88	3636	0.10563	28	0.13301	19	2138	2	2138	2
MV-71A/2	1500	88	5236	0.32664	92	0.12749	29	2064	4	2064	4
MV-71A/4	1553	14	4425	0.22534	154	0.16642	70	2522	7	2522	7
MV-71A/5	1450	32	2732	0.11859	41	0.12293	20	1999	3		
	1500	40	13699	0.12075	31	0.13473	27	2161	3	2161	3
MV-71A/7	1500	88	6369	0.13747	32	0.13375	46	2148	6	2148	6

Italic: not included in the age calculation of the grain

Table 2.- End/Fin

steps with similar ages, suggesting that the Pb had not been disturbed in the whole grain or, if it had, that the disturbance was uniform in each crystal. However, grains #1 and #14, like grains #5 and #8 in the previous sample (MV-48), showed an uncommon behaviour, providing a higher age at the lowest temperature step rather than at the highest temperature step. Grain #8 gave lower ages at the lowest and highest temperature steps (2676 ± 5 - 2681 ± 3 Ma) than that at the intermediate step (2695 ± 7 Ma). Variation in the common lead isotopic composition in different domains within the grain, and consequently an inadequate common lead correction, would explain the results. In the case of #14, however, the $^{206}\text{Pb}/^{204}\text{Pb}$ are high and the uncertainties on the Pb correction cannot be responsible for the difference in the ages. Therefore, the

“reverse” behaviour of the isotopic ratios must be related to a geological origin rather than an analytical origin.

No definitive explanation can be proposed to explain the $^{207}\text{Pb}/^{206}\text{Pb}$ ages because of limitations of the Pb-evaporation method. Only spot methods such as SHRIMP dating, combined with back-scatter electron or cathodoluminescence electron imagery studies of the internal structures of the zircon would be able to help us understand such complex behaviour (see, for example, Pidgeon 1992). Previous work has shown that, in some cases, older ages are not necessarily found in the “most” internal area in the grain (Vavra *et al.*, 1996; Nasdala *et al.*, 1999). Therefore, we interpreted these anomalous older ages of about 2.68-2.70 Ga in grain #1 and #8 as an inherited Pb component in the 2.65 Ga old crystals.

Most of the 10 crystals of the alkali-feldspar granite (sample MV-02) furnished ages at more than one temperature step. Four grains provided a mean $^{207}\text{Pb}/^{206}\text{Pb}$ age value of 2146 ± 3 Ma, whereas four others gave a mean $^{207}\text{Pb}/^{206}\text{Pb}$ age of 2081 ± 3 Ma at each temperature step. The remaining two grains furnished intermediate ages of about 2.13 Ga. The significance of the 2.08 Ga age obtained on four grains remains uncertain but could be related to the hydrothermal episode that affected the granite. Alternatively, it could represent the age of crystallization, with the 2146 Ma age representing an inherited age. This latter hypothesis, however, would imply that the inherited component came from a unique source and that Pb did not undergo any loss, which would be improbable. Therefore, the value of 2146 ± 3 Ma is preferably interpreted as the crystallization age of the granite.

Results obtained in rocks from the Carecuru Domain

Isotopic analyses for the CRD were made on 10 zircon grains from the tonalitic gneiss, 11 grains from the diorite, 9 grains from the enderbite gneiss and 5 grains from the charnockite.

Of the 10 grains from the tonalitic gneiss (sample LT-202A), grains #1, 3, 5 and 6 were from the 150-200 mesh fraction and the other six from the 80-mesh fraction. Most of the grains yielded results at more than one temperature step. The six grains from the coarser granulometric fraction furnished similar ages and provided a mean value of 2150 ± 1 Ma, which is considered to be the crystallization age of the tonalitic protolith. No inherited lead component was identified in the studied grains. All the crystals from the smallest granulometric fraction (grains #1, 3, 5 and 6) yielded slightly younger $^{207}\text{Pb}/^{206}\text{Pb}$ ages (2131 - 2139 Ma) and were not included in the mean age calculation. These lower ages are interpreted as a consequence of Pb-radiogenic loss, probably during the metamorphism that affected the whole grain, whilst the biggest grains did not suffer this loss, at least at the highest temperature step.

Eleven grains from the diorite (sample LT-76) were selected from two distinct granulometric fractions. Grains #1 to #5 came from the finer fraction (150-200 mesh) and grains #7 to #12 came from the coarser fraction (80-150 mesh). Excepting grain #2, all the zircons furnished isotopic results for at least two temperature steps. The crystals from the coarser fraction provided similar isotopic results around 2140 Ma. Grain #5 yielded an age with a large error on the basis of a low number of measured isotopic ratios and was excluded from the mean age calculation. The small grains #1 to 4 gave younger ages, between 2106 Ma and 2137 Ma. Because we considered the small grains to have behaved in the same way as those of

sample LT-202A, the younger ages were not considered for the age calculation. Therefore, based only the six crystals from the coarser fraction, for the crystallization age of the diorite is taken as 2140 ± 1 Ma.

The nine zircon grains from the enderbite gneiss (sample MV-70D) from the Paru Granulitic Nucleus provided $^{207}\text{Pb}/^{206}\text{Pb}$ ages ranging from 2513 Ma to 2600 Ma at the highest temperature step. The two older grains defined a mean $^{207}\text{Pb}/^{206}\text{Pb}$ age of 2597 ± 4 Ma. As for the enderbite gneiss from the Jari Belt, this age is considered as a minimum age for the crystallization of the igneous protolith of the gneiss.

The five grains selected for the age determination of the charnockite (sample MV-71A) from the Paru Granulitic Nucleus showed widely distributed ages in the range of 2.06-2.52 Ga and did not allow a confident determination of the crystallization age. The $^{207}\text{Pb}/^{206}\text{Pb}$ age of 2161 ± 3 Ma obtained on grain #5 could indicate a minimum age for the crystallization of the body or an inherited lead component in a younger grain. Alternatively, the age of 2.06 Ga may represent a maximum age for the crystallization with the older ages reflecting the contribution of different amounts of inherited component. The existence of an Archean inherited lead component was detected in grain #4, with a minimum age of 2.52 Ga.

Discussion and conclusion

The new Pb-Pb geochronological data presented here provide some geochronological references for the tectonic domains proposed by Ricci *et al.* (2001) and allow us to address the four following aspects.

Geochronology of the basement complexes - Archean x Paleoproterozoic domains

New Pb-Pb geochronological records, combined with previously published data, indicate a dominant Archean age pattern for the Jari Belt, Paru Granulitic Nucleus and Cupixi Domain and a dominant Paleoproterozoic age pattern for the Carecuru Domain.

Archean ages of 2652 ± 4 Ma Ga and ≥ 2.80 Ga obtained respectively on TTG gneiss and enderbite gneiss of the Jari Belt, indicate that two magmatic events occurred in this domain during the Neoarchean and Mesoarchean, respectively. Previous geochronological data had shown an Archean evolution. In the northeastern part of the Jari Belt, Montalvão and Tassinari (1984), obtained a Rb-Sr age of 2.90 Ga, and Sato and Tassinari (1999) acquired TDM model ages of 3.06-3.10 Ga. Additionally, Ricci *et al.* (2002) obtained a Pb-Pb age of 2605 ± 6 Ma for a charnockitic pluton that cuts the granulitic orthogneiss in the southeastern part of the Jari Belt.

No geochronological data were provided by this work for the Cupixi Domain. Nevertheless, the Pb-Pb ages of 2.85 Ga and ≥ 2.58 Ga obtained on TTG gneiss and granulitic orthogneiss, respectively, together with previous T^{DM} model ages of 2.92 - 3.36 Ga, acquired on the same rocks (Pimentel *et al.*, 2002; Avelar *et al.*, this volume), indicate a crustal growth event at the Paleo-Mesoarchean transition and date two magmatic events approximately contemporaneous with those identified in the Jari Belt.

In the Carecuru Domain, Archean ages have still not been registered. A TTG gneiss gave an age of 2150 ± 1 Ma, which has been interpreted as the magmatic age of the precursor. Therefore, a Paleoproterozoic age for the formation of the basement rocks is suggested, in contrast to the Archean ages observed in adjacent domains.

In the Paru Granulitic Nucleus, the Pb-Pb age of 2597 ± 4 Ma for an enderbite gneiss, is regarded as the age of the protolith and indicates a Neoproterozoic magmatic event, similar in age to those identified in the Jari Belt and Cupixi Domain. Such a record, together with geophysical, structural and lithological contrasts, suggests that the Paru Granulitic Nucleus could represent an Archean inlier within the Paleoproterozoic Carecuru Domain.

The fingerprint of the Transamazonian Orogeny

The fingerprint of the thermo-tectonic Transamazonian Orogeny is widely registered in the studied region, spreading across the boundaries of the tectonic domains.

The first geochronological records of the Paleoproterozoic magmatism are provided by ages of 2150 ± 1 Ma and 2140 ± 1 Ma for TTG gneiss and diorite in the Carecuru Domain, and 2146 ± 3 Ma for an alkali-feldspar granite in the Jari Belt. A charnockitic pluton of the Paru Granulitic Nucleus was analysed, and is also probably related to the Paleoproterozoic magmatism even though its age is poorly constrained. Therefore, a very restricted range of ages, between 2.14-2.15 Ga, has been obtained for the Transamazonian magmatism, despite the wide range of petrographic composition.

In French Guiana and in the central-northern region of Amapá State, the Paleoproterozoic magmatism extends between 2.25 and 2.08 Ga (Vanderheague *et al.*, 1998; Nogueira *et al.*, 2000; Delor *et al.*, 2001a; Avelar 2002). Tonalitic and trondhjemitic magmatism occurred at 2.2-2.17 Ga, calc-alkaline magmatism (diorite, tonalite and associated felsic volcanism) took place at about 2.18 - 2.13 Ga, and Mg-K rich granite and leucogranite were emplaced between 2.10-2.08 Ga.

The age of 2140 ± 1 Ma obtained for a diorite of the Carecuru Domain is within the range of ages furnished by calc-alkaline magmatism elsewhere in the eastern Guiana

Shield. On the other hand, the age of 2146 ± 3 Ma acquired on the alkali-feldspar granite from the Jari Belt is significantly older than the leucogranitic magmatism recognized in the other areas.

The Transamazonian Orogeny in the area is also characterized by metavolcano-sedimentary sequences. McReath and Faraco (1997) and Faraco (1997) registered Sm-Nd ages between 2.26 and 2.19 Ga in metamafic rocks of one of the sequences located at the boundary between the Carecuru Domain and Jari Belt, in agreement with other Sm-Nd, U-Pb and Pb-Pb ages available in greenstones of the eastern Guiana Shield (Gibbs and Olszewski, 1982; Gruau *et al.*, 1985; Norcross *et al.*, 2000; Delor *et al.*, 2001b).

Felsic metavolcanic rocks are well known in French Guiana where they have been dated at 2.14 - 2.16 Ga (Delor *et al.*, 2001b). In the studied area of central and northern Amapá State, rhyolite dated a late-orogenic volcanism at about 2.05 Ga (Rosa-Costa *et al.*, 2002b), which is coeval with the granitoid and charnockite emplacement at 2.05-2.06 Ga (Avelar *et al.*, 2001; Lafon *et al.*, 2001). This result, together with the age of 2.15 Ga for the alkali-feldspar granite, suggests that the geotectonic context of the studied area may have been different from those of the northern domains in the southeastern Guiana Shield.

Age of high-grade metamorphic episode and relationships with igneous charnockite

In the Bakhuis Mountains of northeastern Suriname, a Late Transamazonian high-grade thermal event (the Ultra High Temperature event) has been recognized at 2.07 - 2.06 Ga (Delor *et al.*, 2001c; Delor *et al.*, this volume). In the central and northern regions of Amapá State, the 2.05 - 2.06 Ga old charnockitic magmatism has also been related to this Late-Transamazonian high-grade thermal event (Avelar *et al.*, 2001; Lafon *et al.*, 2001). In the central region, a Late-Transamazonian age for the high-grade episode has also been identified in Archean granulitic gneiss by Sm-Nd dating on metamorphic minerals, which furnished isochronic ages of around 2.03 - 2.0 Ga on whole rock and garnet (Oliveira, 2002).

The age of granulitic metamorphism in the studied area and its relationships with charnockite magmatism remain an unresolved problem. Due to the lack of the definitive data, it has not been possible to determine whether this metamorphic event represents the same episode as that identified in the other areas of the eastern Guiana Shield.

The existence of large units of granulitic gneiss, together with charnockitic plutons, strongly indicates that the whole area underwent a high-grade metamorphic episode. In the Jari Belt, the Pb-Pb ages of the granulitic

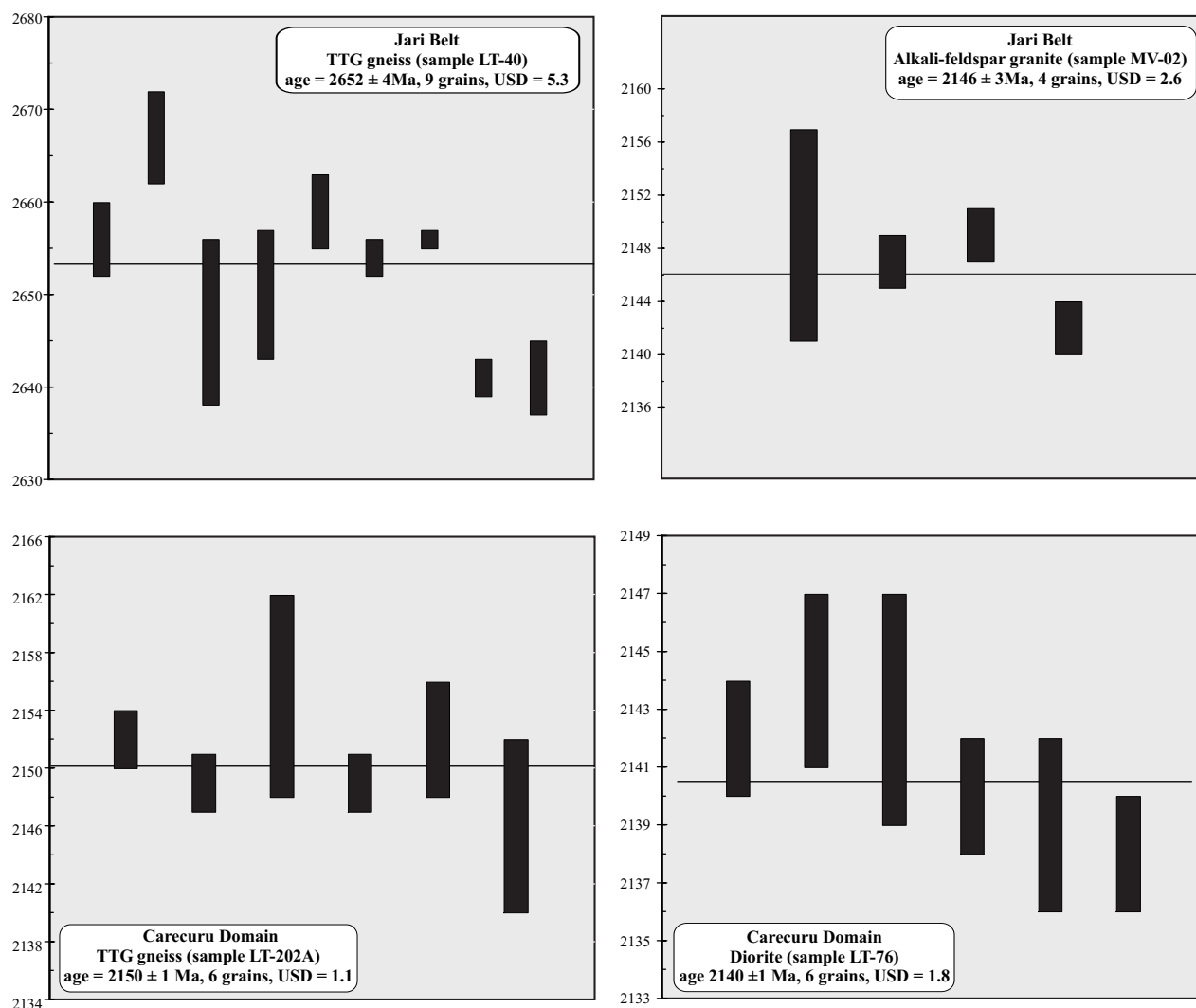


Fig. 5.- Mean values of the Pb-Pb ages for the dated zircons.

Fig. 5.- Moyennes pondérées des âges Pb-Pb obtenus pour les zircons datés.

gneiss (≥ 2.80 Ga) and charnockitic magmatism (2605 ± 6 Ma Ga, Ricci *et al.*, 2002) suggests an Archean age for the high-grade episode. In contrast, in the Paru Granulitic Nucleus, the Pb-Pb dating suggests a Paleoproterozoic age for the charnockite (2.06 – 2.15 Ga) while the granulitic gneiss furnished an Archean age for the magmatic protolith (2597 ± 4 Ma), but no metamorphic age can be determined.

Relationships with Archean Carajás domain

Two main proposals are available for dividing the Amazonian Craton into large tectonic provinces (Tassinari *et al.*, 2000 and Santos *et al.*, 2000). The limits between provinces in the eastern part are still under discussion, as is the extension of preserved or reworked Archean crust in the Paleoproterozoic domains. The proposal of Tassinari *et al.*, (2000) is based on the age of the late orogenesis that affected the provinces -they extended the southward extent of the

Maroni-Itacaiúnas Province (Paleoproterozoic) up to the northern limit of Archean Carajás region (southeastern limit of the Amazonia Central Province), even though Archean remnants are well represented in southern sections of the Maroni-Itacaiúnas Province. On the other hand, the proposal of Santos *et al.* (2000) is based on the age of the rock formations, independent of whether or not they are affected by the Transamazonian Orogeny -they extend the Archean Carajás Province up to the central Amapá region.

The Archean ages recognized in the studied area permit the characterization of an extended Archean crustal segment from the Ipitinga Lineament to the central region of Amapá State (Tartarugal region), which was intensely reworked during the Transamazonian Orogeny.

This Archean crustal segment was accreted during a period of crustal growth at the Paleo- Mesoarchean transition (Sato and Tassinari, 1997; Pimentel *et al.*, 2002; Avelar *et al.*

this volume) and two magmatic episodes are registered during Meso- and Neoproterozoic times. Mesoarchean crust/mantle differentiation and Mesoarchean magmatic episodes, i.e. older than 2.79 Ga, are well documented in the Carajás area of the Amazonian Central Province (Macambira and Lafon, 1995; Tassinari *et al.*, 2000), but the Neoproterozoic episode (ca. 2.58-2.63 Ga) corresponds mainly to a volcanic episode in an extensional context (Machado *et al.*, 1991; Trendall *et al.*, 1998). Therefore, the Archean segment of the southeastern Guiana Shield underwent a different evolution from the Archean Carajás region during Neoproterozoic times.

The Carecuru Domain has not provided any Archean ages, which strongly suggests that Paleoproterozoic domains exist between the Carajás area and the south of the Ipitinga Lineament. This assumption is reinforced by the Paleoproterozoic Rb-Sr ages on metamorphic rocks and

Pb-Pb ages in granitoid from the segment northward from Carajás range (Santos *et al.*, 1988; Macambira *et al.*, 2001).

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Appendix A

Petrographic descriptions of dated samples

Sample MV-48

A medium-coloured and medium-grained enderbitic gneiss. The mineralogy is represented by antiperthitic plagioclase, quartz, green-brown hornblende, reddish-brown biotite, orthopyroxene, and minor opaque minerals, clinopyroxene, apatite and zircon. Retrograde metamorphic alteration features are observed, such as chloritization of the biotite and sericitization of the plagioclase.

Sample LT-40

A tonalitic gneiss mainly composed of plagioclase, quartz, microcline and biotite, plus allanite, apatite and zircon. Its gneissic texture is defined by interlayered granoblastic and lepidoblastic bands. Biotite, locally altered to muscovite, and saussuritized plagioclase are evidence of retrograde metamorphism.

Sample MV-70D

A medium- to fine-grained enderbitic gneiss, light-coloured, consisting of antiperthitic plagioclase (sericitized), quartz, orthopyroxene, and minor opaque minerals, clinopyroxene, biotite (partly altered to chlorite) and zircon. This rock presents a macroscopic gneissic texture and microscopic granoblastic texture. Retrograde metamorphism to greenschist facies is indicated principally by chloritization of the biotite, sericitization of the plagioclase, and partial substitution of orthopyroxene by secondary biotite.

Sample LT-202A

A medium-coloured and medium-grained tonalitic gneiss mainly consisting of plagioclase, quartz, hornblende and biotite, plus opaque minerals, apatite, sphene and

zircon. The texture is porphyroclastic, defined by phenocrysts of plagioclase and hornblende, within a recrystallized matrix. Evidence of retrograde metamorphic/hydrothermal alteration is registered, such as hornblende altered to biotite, chloritization of the primary biotite and sericitized plagioclase.

Sample MV-71A

A coarse-grained and light-coloured charnockite. The mineralogy is composed of mesoperthite (microperthitic plagioclase), quartz, antiperthitic plagioclase, reddish-brown biotite, orthopyroxene altered to secondary biotite, widespread opaque minerals, apatite and zircon. The texture is porphyritic, showing relatively large phenocrysts of mesoperthite, within a recrystallized and deformed medium-grained matrix.

Sample LT-76

A diorite. The main minerals are slightly sericitized plagioclase, mafic minerals (chloritized biotite and hornblende associated with epidote) and minor quartz, opaque minerals, apatite and zircon. The rock is medium to coarse grained and presents a heterogranular hypidiomorphic texture, showing evidence of deformation and recrystallization.

Sample MV-02

An alkali-feldspar granite. The rock is leucocratic, fine to medium grained, and consists essentially of quartz and alkali feldspar, plus plagioclase (albite), sphene and zircon. The alkali feldspar is strongly argillized. The chlorite occurs as a secondary mineral and carbonate fills veinlets. The texture is inequigranular granoblastic, and locally protocataclastic.