



The neoproterozoic Mantiqueira Province and its African connections: a zircon-based U–Pb geochronologic subdivision for the Brasiliano/Pan-African systems of orogens

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Abstract

The Mantiqueira Province (MPV) is a large, complex structural province deformed by the Neoproterozoic/Early Paleozoic Brasiliano Orogenic event in South America. Its evolution is herein detailed on the basis of the geological and geometric characterisation, structural and thermal overlapping of the distinct phases of the orogenic collage. In addition to the tectono-structural analysis, some 50 new zircon U–Pb SHRIMP data from a large number of selected units provided a powerful tool for understanding the granitic chronostratigraphy and the orogenic evolution. We also integrated existing U–Pb analyses, totalling some 240 determinations, which also furnished important constraints to delineate the precise tectono-magmatic succession (orogenic episodes).

The study delineated a highly complex evolution, comprising three successive systems of orogens: Brasiliano I, II and III. New crustal growth including juvenile intraoceanic volcano-plutonic arcs characterises the earlier Brasiliano I orogenic system, which presents collisional climaxes at ca. 790 Ma (Embu Domain) and 730–700 Ma (São Gabriel Orogen). On the other hand, recycling of pre-existing crustal sources are the dominant processes operating within the systems Brasiliano II and III. The collisional climaxes within the Brasiliano II are recorded at 640–620 Ma (Dom Feliciano Orogen) and 600 Ma (Paranapiacaba and Rio Piên orogens), whereas the Brasiliano III climaxes are bracketed between 590–560 Ma (Araçuaí Orogen) and 520–500 Ma (Búzios Orogen).

The available geochronological data from the Pan-African literature suggests temporally similar orogenic succession. The protracted, dominantly accretionary, Pan-African I system lasts from 850 to 700 Ma, whereas the Pan-African II (collisional peak at 650–600 Ma) and the Pan-African III (collisional peak at 590–540 Ma) are characterised dominantly by crustal recycling

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processes. The study reinforced previous attempts to correlate the northernmost Araçuaí Orogen and the West Congo Orogen (AWCO), both belonging to the system Brasiliano/Pan-African III. Additionally, our study does not confirm models for a direct linkage between the south-eastern orogens from Ribeira and Dom Feliciano belts (Brasiliano II) and the south-western African orogens, i.e. Kaoko, Damara, Gariep, and Saldania (Pan-African III).

Finally, taking advantage of the large U–Pb SHRIMP database, we also reassessed the extent of the Brasiliano reworking on the Archean/Paleoproterozoic basement, namely on the controversial and poorly constrained eastern margin of the São Francisco Craton.

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1. Introduction

The Mantiqueira Province (MPV) of Almeida et al. (1981) is a major (ca. 700,000 km²) and highly complex structural province deformed by the Brasiliano “Orogenic Cycle” in South America, during the Neoproterozoic/Early Paleozoic (900–480 Ma). It extends from 33° S in Uruguay to the southern border of Bahia State, Brazil (15° S). It is nearly 3000 km long, averaging 200 km wide, and it is parallel to the South American Atlantic coast along the eastern margins of the Rio de La Plata and São Francisco Cratons (Fig. 1). Owing to its geographical location, flanking south-eastern South American and facing Africa, the province is a key element for unravelling connections between Brasiliano and Pan-African orogens during the amalgamation of the W Gondwana Supercontinent (Fig. 1).

Structural studies since the early 1980s suggested the MPV evolved as a Himalayan-type diachronic oblique continent-continent collision between South American and African cratons. Early E–W, WNW–ESE or NW–SE syn-collisional tectonics, followed by development of NE–SW, NNE–SSW transpressional (dextral) shear zones, accommodated the orogenic stresses (e.g. Figueiredo and Campos Neto, 1993; Fernandes et al., 1992; Heilborn et al., 1995; Machado, 1997; Ebert and Hasui, 1998; Pedrosa-Soares and Wiedmann-Leonardos, 2000; Campos Neto, 2000; Trouw et al., 2000). Hence, the evolution of the distinct orogens is a response to continental collision processes, by means of transpressional late-orogenic belt-parallel tectonics, responsible for the development of extended deep shear systems. In most cases, the systems are the limits of distinct terranes and separate distinct records of orogenic magmatism, deformation and metamorphism. Accordingly, the re-articulation of the

distinct terranes, during the Neoproterozoic collage, giving rise to the present intricate NE-trending mosaic, characterises the main tectonic pattern of the province (Figs. 1 and 2a, b). Additionally, the transpressive systems control the opening of the volcanic-sedimentary basins, the generation of syn-transcurrent crustal plutons, and the terminal intrusion of the post-orogenic batholiths.

The present study is based on two decades of systematic field and laboratory research on the MPV geology by the senior author, at the Geological Survey of Brazil (CPRM). It was supported also by systematic exchange of information with researchers from several Brazilian universities, from the South African Council for Geoscience and from the University of Stellenbosch. These studies included field and laboratory work on both continents, with results published elsewhere (Chemale et al., 1995; Babinski et al., 1996, 1997; Gresse et al., 1996; Silva et al., 1999, 2000a, 2000b; Hartmann et al., 2000a). The synthesis of these studies was integrated into a Ph.D. Thesis (Silva, 1999) and a (GIS)-based geological and geochronological compilation of the entire MPV, at 1:2,500,000.000 scale (Silva et al., 2003b).

The integration of some 50 new zircon U–Pb SHRIMP analyses, partly complemented by Sm–Nd data from the southern, central-north and north domains of the province, provide the main geochronological support for this study. New U–Pb SHRIMP analyses (Table 2) were obtained in cooperative projects with the Australian National University and the University of Western Australia.

The critical analysis and integration of the existing U–Pb ages from the province literature, complemented by the analyses shown in Table 2 furnished consistent support for the overall interpretation of the orogenic

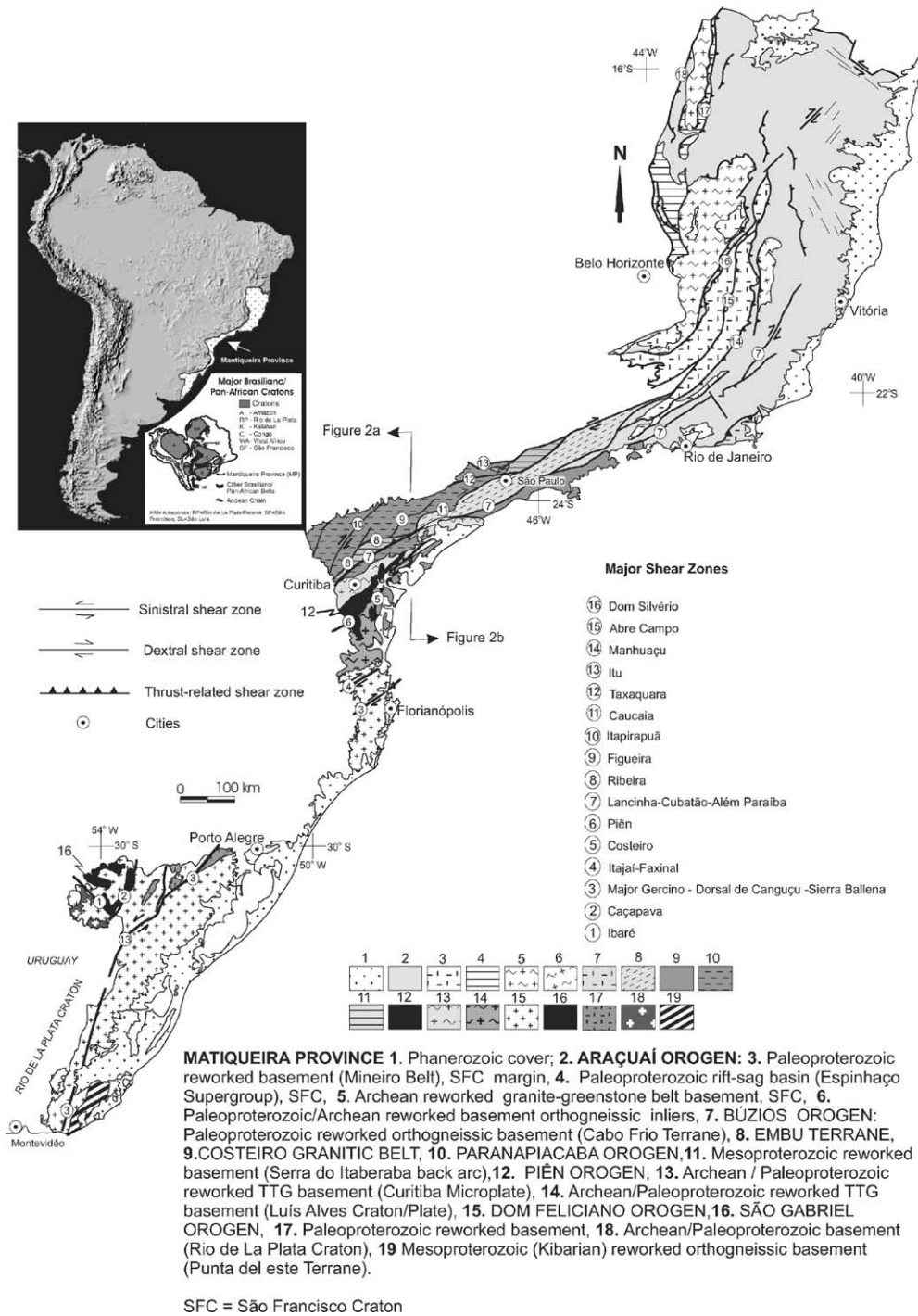


Fig. 1. Simplified tectonic map of the Mantiqueira Province's orogens and terranes, modified from Siva et al. (2002e, 2002f) and Delgado et al. (2004). The inset displays the probable Mantiqueira Province position, during the assembly of the SW Gondwanaland, at ca. 560 Ma (system of Orogens Brasiliano/Pan-African III) (Digital topography of South American from the USGS).

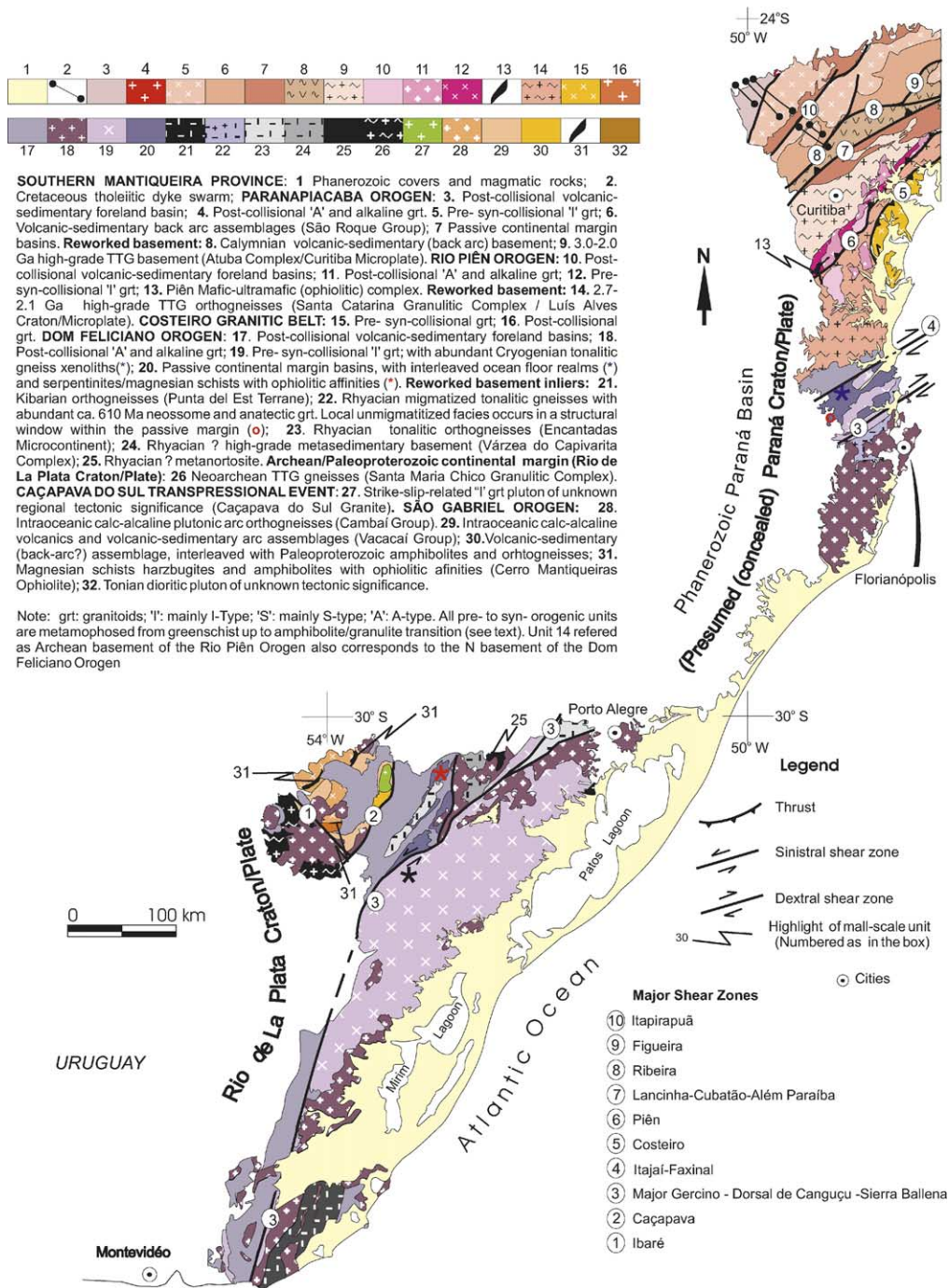


Fig. 2. Geological map simplified (and modified) from the GIS-based (a) “Geological Map of the Mantiqueira Province”, Scale 1:2,500,000 (Silva et al., 2002d) (Arcview edition by Joseneusa Brilhante Rodrigues) and (b) “Geological Map of the Mantiqueira Province”, Scale 1:2,500,000 (Silva et al., 2002d) and the “Geological Map of Minas Gerais State, Scale 1:1,000,000 (Silva et al., 2002e) (Arcview edition by Joseneusa Brilhante Rodrigues).

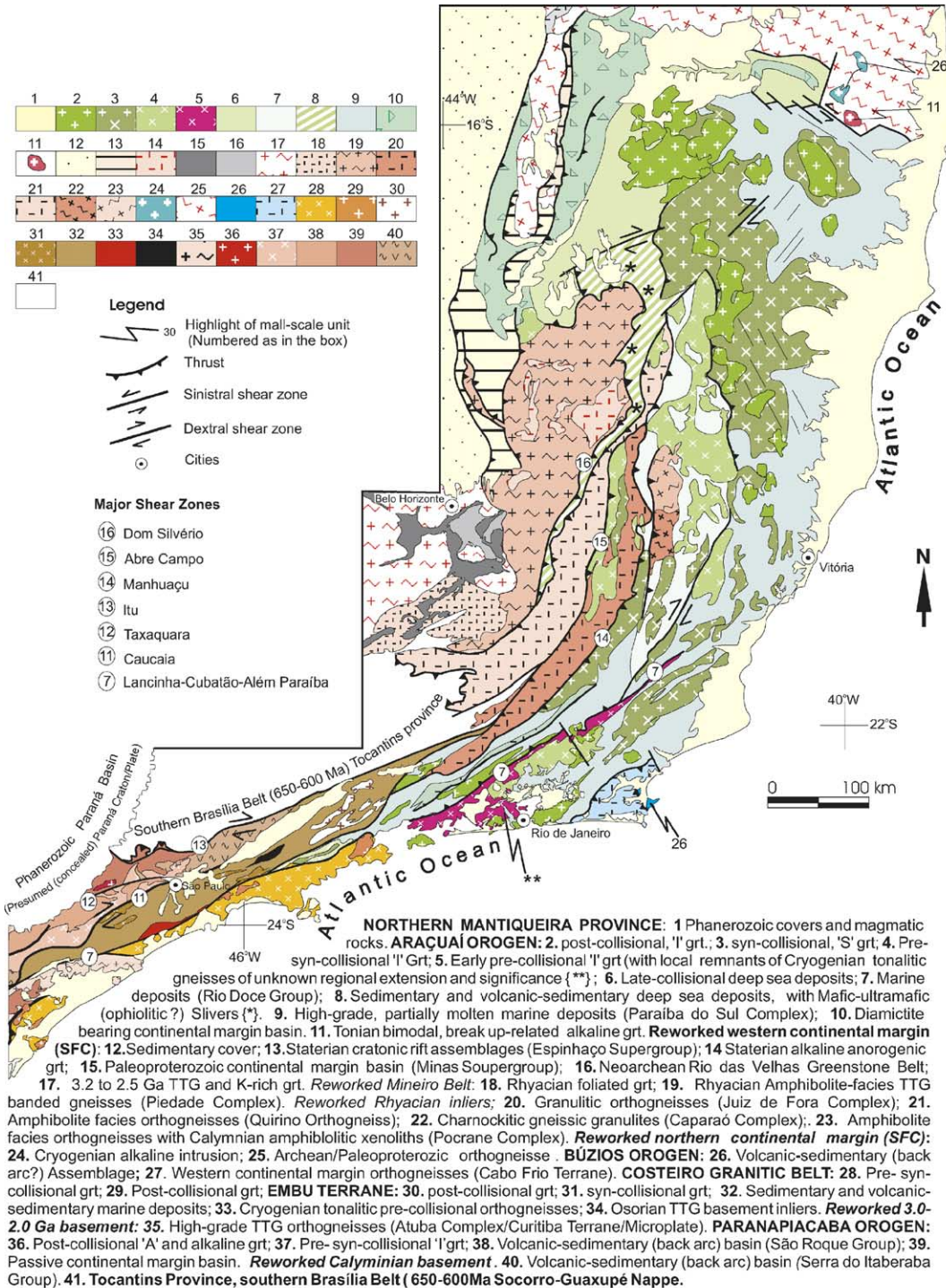


Fig. 2. (Continued).

evolution. Readers interested in this complete synthesis, totalling some 220 analyses, should access the “Table A (Supplementary data)”, archived in the electronic data depository from the Precambrian Research Website.

2. Geological setting: the polycyclic MPV

The MPV is a mosaic of distinct Neoproterozoic terranes that, collectively, comprise several systems of orogens, preserving important infracrustal and supracrustal paleotectonic remnants ascribed to Archean, Paleoproterozoic and Mesoproterozoic megacycles. The Brasiliano systems includes (Figs. 1 and 2a, b):

- (i) Neoproterozoic rifted continental margin successions, locally (in the northern segment) containing representatives of two Neoproterozoic, pre-Sturtian glaciogenic events. These successions were metamorphosed under greenschist to granulite facies conditions during the Neoproterozoic collage and represent overthrust, metasedimentary thrust-fold basins;
- (ii) widespread Neoproterozoic-Cambrian granitoids including pre-syn- to post-tectonic I-type, S-types, A-types, and alkaline associations. In the northern domain, the post-tectonic granitoids are dominantly polydiapiric, zoned, I-Caledonian plutons; minor pre-collisional, juvenile expanded calc-alkaline associations are also represented;
- (iii) syn-orogenic arc-related sedimentary basins and volcanic-sedimentary back arc assemblages;
- (iv) dismembered ophiolite and ocean floor remnants associated with juvenile, pre-collisional, intraoceanic arcs;
- (v) late- to post-collisional volcanic-sedimentary basins;
- (vi) Archean, Paleoproterozoic and Mesoproterozoic remnants of partially reactivated terranes that underwent Neoproterozoic overprint under greenschist to granulite-facies conditions.

The study characterised distinct collisional/magmatic/metamorphic peaks, following Sengör's (1990) observations of multiple collisional pro-

cesses within an orogenic zone, spanning from 880 to 500 Ma.

2.1. Review of MPV geotectonic and geographical appellations

Orogen-parallel tectonic events represented by three major orogenic belts were responsible by the present extended NE-SW-trending (south domain) and the NNE-SSW-trending inflexion at the north domain. The major orogenic belts, Dom Feliciano, Ribeira and Araçuaí, comprise seven orogens, discontinuously exposed and with some poorly constrained limits. As a consequence, some segments of the province have received a large number of tectonic and regional designations, often with conflicting significance. One of the most controversial issues on the tectonic evolution is the definition of the boundary between the Araçuaí Orogen and the Ribeira Belt. The internal organisation of the Ribeira Belt, especially its northernmost termination is another matter of dispute in the literature. Some authors (Brito-Neves et al., 1999; Campos Neto, 2000; Vlach, 2001; Cordani et al., 2002) suggest that Embu Complex constitutes a displaced terrane, attached to the north-east domain of the Ribeira Belt (Paranapiacaba Orogen), during the late Brasiliano collage. Other authors (Wernick et al., 1993; Töpner, 1996, 1997; Dantas et al., 2000), based on the similar ages of syn- and post-tectonic magmatism (630–590 Ma) and similar (Paleoproterozoic) Nd model-ages from the basement of all tectonic domains, concluded that they shared (at least a final) common tectonic-magmatic evolution, and hence could not represent amalgamated exotic terranes. Presently, we are unable to resolve these crucial controversies, and we believe they are likely to remain controversial, until new detailed cartographic, geophysical, structural, and isotopic studies become available. These uncertainties are not a major concern for a descriptive review study like the present, so for the purpose of this paper we adopted, with minor modifications, the tectonic organisation proposed by Brito-Neves et al. (1999), Campos Neto (2000), Cordani et al. (2002). Accordingly, in the present text, the north domain of the MPV comprises the Araçuaí and Búzios orogens (Araçuaí Belt, and the northernmost segment of the Ribeira Belt). The central domain of the province is composed of the Paranapiacaba and Rio Piên orogens, the Embu Terrane and the

Table 1

Main geotectonic and geographical appellations for the major orogenic units and events within Mantiqueira Province

SOUTHERN DOMAIN RS, SC and UY				SOUTH-CENTRAL DOMAIN PR, SP, MG, RJ				NORTH DOMAIN MG, ES, BA				
<i>DOM FELICIANO BELT (Fragoso-César, 1980)</i>				<i>RIBEIRA BELT (Almeida et al., 1973)</i>				<i>ARAÇUAÍ BELT (Almeida et al. 1973)</i>				
Chemale Jr. et al. (1995a,b) Vila Nova Tijucas Dom Feliciano Belt (Dom Feliciano Event) Vila Nova Belt São Gabriel Orogeny				Figueiredo and Campos Neto (1995) Socorro-Guaxupé Thurst-Nappe (*) Brasiliano I Orogeny (Apiáí Folded Belt)				Rio Doce Orogeny (Costeiro Belt, Serra do Mar Microplate)	Araçuaí Belt			
Not focused				Heilbron and Machado (2003) Brasília Belt				Occidental Terrane	Oriental Terrane	Cabo Frio Terrane	Araçuaí Belt	
Dom Feliciano Fold Belt				Trouw et al. (2000) Brasília Fold Belt (*) 1 th Orogenic Stage (*)				Ribeira Fold Belt Juiz Fora Terrane 2 th Orogenic Stage	Rio Doce Orogeny	Cabo Frio Terrane	3 th Orogenic Stage	Araçuaí Fold Belt
Chemale Jr. et al. (1995b) São Gabriel Tijucas Dom Feliciano Belt (Dom Feliciano Event) Vila Nova Belt				Schmitt (2000) Not focused				Rio Doce Orogen	Búzios Orogen	Not focused		
São Gabriel Tijucas Dom Feliciano Belt				Babinski et al. (1996, 1997) Not focused						Not focused		
São Gabriel Tijucas Dom Feliciano Orogen (Passinho Orogen)				Hartmann et al. (2000a) Not focused						Not focused		
São Gabriel Schist Granitic Belt Punta del Este Terrane				Basei et al. (2000) Apiáí (Ribeira) Fold belt				Rio Doce Orogen		Not focused		
São Gabriel Tijucas Pelotas Punta del Este Orogen Belt Batholith Terrane				Campos Neto (2000) Paranapiacaba, Rio Piên orogens, Embu Terrane and (Socorro-Guaxupé Orogen *)				Rio Doce and Rio Negro orogens	Rio Cabo Frio Orogen	Araçuaí Orogen		
São Gabriel Dom Feliciano Orogen				THIS STUDY Punta del Este Terrane Paranapiacaba, Rio Piên, and Embu Terrane and (Socorro-Guaxupé Orogen *)				Araçuaí Orogen (SE domain)	Búzios Orogen	Araçuaí Orogen (NW domain)		

Acronyms: BA, ES, MG, PR, RJ, RS, SP, SC, UY stand for: Bahia, Espírito Santo, Minas Gerais, Paraná, Rio de Janeiro, Rio Grande do Sul, São Paulo and Santa Catarina states and Uruguay, respectively. (*) southern extension of the Tocantins Province-Brasília Belt, Socorro-Guaxupé Orogen, overprinted by the Araçuaí Orogeny

Costeiro Granitic Belt (a minor domain of uncertain tectonic significance), all ascribed to the main segment of the Ribeira Belt. Finally, the Dom Feliciano Orogen (Dom Feliciano Belt) and São Gabriel Orogen (Vila Nova Belt) constitute the southernmost tip of the province. Table 1 summarises the main evolutionary models for the orogenic/tectonic evolution and the consequent intricate and, at some extent, conflicting nomenclature.

2.2. Reactivated Archean, Atlantikan and Rodinian remnants in MPV

Archean and Paleoproterozoic “basement” gneisses, are almost continuously exposed at the north domain of the province, the Araçuaí Orogen. The north-west and north limits of the orogen are the west continental margin of the São Francisco Craton/Plate (Fig. 2b; Table 2), whereas the opposite (eastern) continental margin, probably corresponding to a segment of the Congo Craton (e.g. Pedrosa-Soares et al., 2001), is not so well defined.

In central and southern domains of the province, owing to the extended exposure of the Phanerozoic cover of the Paraná basin, which conceals most of the western margin of the Paranapiacaba, São Gabriel and Dom Feliciano Orogens, there are only minor segments of exposed basement units, mostly as small basement inliers (Fig. 2a and b; Table 2). Accordingly, the role that these severed basement segments played from break-up to reconstruction of this sector of the south-western Gondwana remains uncertain.

The original configurations of the continents that rifted and drifted away (São Francisco, Rio de La Plata, Paraná, Congo and Kalahari plates?) are not well-defined and the ones that took their place are, so far, speculative. Recent research (Kröner and Cordani, 2003; Pisarevsky et al., 2003) suggests new possible configurations for the Rodinian assembly and fragmentation. Both studies delineate important consequences for the intracontinental adjustment of South American and South African Neoproterozoic belts. The present re-interpretation of a large number of U–Pb ages is an attempt to minimise these uncertainties in Brazil, especially with respect to one of the most controversial subjects from the Brazilian literature, the highly reworked south-eastern limits of the São Francisco Craton (Fig. 2b).

3. Mantiqueira multi-episodic orogenic collage and the systems of orogens Brasileiro I, II, and III

The present correlation study based on the tectonic-magmatic and isotopic signatures of the orogenic magmatism within the entire province is based on some 180 U–Pb crystallisation ages obtained in some 160 key pre-, syn- and post-orogenic units. This updated database was crucial for this first attempt to the discrimination the precise time intervals for all pre-, syn- and post-orogenic metamorphic and magmatic stages from the entire province. Complementary to the radiometric ages, the chemical and tectonic-magmatic classification of each pluton were also tabulated, respecting wherever possible, the original authors’ classifications. The complete crystallisation and metamorphic age record is tabulated in Table 2 and A. The latter (A), includes the complete references of the sources of the ages and is organised accordingly to the seven orogens which constitute the province; within each orogen it is internally organised, accordingly to the successive pre-, syn- and post-orogenic phase. Table A (Supplementary data) can be accessed in the electronic data depository with Precambrian Research Website.

The orogenic evolution of the MPV is herein analysed according to Sengör (1990) by which orogenic belts are the result of the activity of a large number of convergent (in space and in time) plate boundaries, i.e. orogenies. The amalgamation of the convergent plate boundaries products (orogens) gave rise to the Neoproterozoic orogenic collage, by means of a diachronous, long lasted succession (systems) of orogens (Brito-Neves et al., 1999; Silva, 1999; Campos Neto, 2000). Within the Pan-African belts these multiple orogenic collage systems have long been recognised. Porada (1989) discriminates between an earlier (900–750 Ma) Katangan, and a later (750–500 Ma) Damarian orogenic ‘episodes’. This major division has been confirmed by other studies, including Trompette et al. (1993), who distinguished an older, long-lived and more ubiquitous orogenic ‘episode’, lasting from ca. 1000 to 600 Ma, and a younger, short-lived ‘episode’, bracketed between ca. 600 and 540 Ma. At the same time, Black and Liégeois (1993) delineated a polyphase evolution for the Pan-African Cycle in the Saharan African domain, represented by earlier (730–650 Ma) juvenile, Pan-African ‘accretionary

Table 2

Zircon U–Pb SHRIMP, U–Pb conventional, Pb–Pb evaporation and Sm–Nd data on granitoids, orthogneisses and felsic volcanics related to the systems of orogens from the Mantiqueira Province (southeastern Brazil) and from the Saldania Belt (south-western Africa)

Dated unit	Crystallisation age (Ma)	Metamorphic overprinting age (Ma)	Model T_{DM} age (Ma)	$\epsilon_{Nd}(t)$	Reference
System of orogens Pan-African III (Saldania Orogen)					
Syn-collisional plutons (South Africa)					
Riviera Pluton (SA)	n.a.		1234	–2.6 ($t=550$)	Silva et al. (1997a, 2000a)
Robertson Pluton (SA)	536 ± 5		1626	–3.1 ($t=550$)	Silva et al. (1997a, 2000a)
Darling Batholith (SA)	547 ± 6		1561	–3.5 ($t=550$)	Silva et al. (1997a, 2000a)
System of orogens Brasileiro III (Araçuaí Orogen)					
Post-collisional plutons from the northern domain (ES and MG)					
Younger facies of Nanuque Batholith	532 ± 10		n.a.		L.C. da Silva (unpublished data) (*)
Younger facies of Muniz Freire Batholith	500 ± 4		n.a.		L.C. da Silva (unpublished data) (*)
Syn-collisional plutons from the southern domain (RJ)					
Rio de Janeiro Suite (Pão de Açúcar granite)	559 ± 4		n.a.		Silva et al. (2003a)
Rio de Janeiro Suite (Corcovado granite) (RJ)	560 ± 7		n.a.		Silva et al. (2003a)
Syn-collisional plutons from the northern domain (MG)					
Nanuque Suite	573 ± 5	508 ± 8 (1σ)	n.a.		Silva et al. (2002a)
Manhuaçu Charnockite	584 ± 5		n.a.		Silva et al. (2002a)
Governador Valadares I gneissic granite	565 ± 31		n.a.		Silva et al. (2002a)
Governador Valadares II gneissic granite	561 ± 7		n.a.		Silva et al. (2002a)
Pre- to syn-collisional pluton from the southern domain (RJ)					
Serra do Órgãos Batholith (RJ)	569 ± 6		n.a.		Silva et al. (1999)
(Early) pre-collisional plutons from the northern domain (MG)					
Cuité Velho Tonalite	630 ± 3		n.a.		L.C. da Silva (unpublished data) (*)
Anorogenic plutons ascribed to the break up of the pre-Araçuaí continental crust: northern domain (BA)					
Salto da Divisa anorogenic bimodal granitic suite	875 ± 9		n.a.		Silva et al. (2002a)
Western basement of the Araçuaí Orogen: reworked São Francisco Craton/plate margin (MG)					
Guanhães TTG gneissic complex					
N of Coluna Town	2867 ± 10		n.a.		Silva et al. (2002a)
São João Evangelista quarry	2711 ± 11	519 ± 5 (1σ)			Silva et al. (2002a)
São Pedro do Suaçuá granite	2710 ± 6	497 ± 68 (li)			Silva et al. (2002a)
Archean units of uncertain tectonic significance (MG)					
Juiz de Fora Complex ?	2985 ± 17	2856 ± 44 M_1 808 ± 360 M_2 (li)			Silva et al. (2002a)
Barbacena TTG gneiss	~2500 ?	2068 ± 19 M_1 (li)			Silva et al. (2002a)
Lima Duarte Gneiss	2777 ± 22	1137 ± 280 (li)			Silva et al. (2002a)
Mineiro Belt/Piedade Complex (former Mantiqueira Complex) (MG)					
Piedade TTG Gneiss	2169 ± 44				Silva et al. (2002a)
Ponte Nova TTG Gneiss	2079 ± 11	2044 M_1 ?			Silva et al. (2002a)

Table 2 (Continued)

Dated unit	Crystallisation age (Ma)	Metamorphic overprinting age (Ma)	Model T_{DM} age (Ma)	$\epsilon_{Nd}(t)$	Reference
Rio Pomba TTG Gneiss	2169 ± 44	2028 ± 66 M ₁ 540 ± 11 M ₂ (li)			Silva et al. (2002a)
Ewbank da Câmara TTG Gneiss	2052 ± 26 (ui)	443 ± 240 M ₁ (li)			Silva et al. (2002a)
São Tiago Foliated granite	2050 ± 12	565 ± 23 (1 σ)			Silva et al. (2002a)
Rio Pomba quarry charnockite	2100				L.C. da Silva (unpublished data) (*)
Caparaó Complex (MG)					
Caparaó Charnockite Granulitic	2195 ± 15	587 ± 9 M ₁			Silva et al. (2002a)
Anorogenic intracratonic Borrachudos Metagranitic Suite (MG)					
Porto Açucena Metagranite	1740 ± 8	? 223 ± 220 M ₁ (li)			Silva et al. (2002a)
Amphibolitic paleodykes within Pocrane Complex (MG)					
Bananal amphibolite	1506 ± 14	602 ± 14 (1 σ)			Silva et al. (2002a)
Northern basement of the Araçuaí Orogen: reworked São Francisco Craton/plate margin (BA)					
Ihêus charnockitic granulite	2719 ± 10	711 ± 9 (1 σ)			Silva et al. (2002b)
System of orogens Brasiliano II (Dom Feliciano Orogen) (SC and RS)					
Post-collisional magmatism from the northern Domain (SC)					
Tabuleiro Suite	597 ± 9		1691	-5.6 ($t=600$)	Silva and McNaughton (2004)
Guabiruba Suite	610 ± 6		2525	-22 ($t=600$)	Silva and McNaughton (2004)
Valsungana II granite	593 ± 9		2344	-4 ($t=600$)	Silva et al. (2003a)
Alto Varginha granite	579 ± 8				Silva et al. (2003a)
Forquilha Tonalite vicinities of Vargem Grande town	611 ± 3				Silva et al. (2002c)
Forquilha Tonalite Rancho Queimado Road	608 ± 7				Silva et al. (2002c)
Itajaí Basin tuff	606 ± 8				Silva et al. (2002c)
Syn-collisional magmatism from the northern Domain (SC)					
Paulo Lopes Suite	626 ± 8 640 ± 59 ^b		1682	-7.7 ($t=600$)	Silva et al. (2003a) Silva et al. (1997b)
Brusque Group felsic metavolcanics	637 ± 11				L.C. da Silva (unpublished data)
Águas Mornas banded anatectic granite	639 ± 13 592 ± 5 (li)#		1753	-5.77 ($t=650$)	Silva and McNaughton (2004)
Camboriú granitic migmatitic complex					
Caseca quarry banded anatectic granite	~10–630li #		2862	-25.3	Silva and McNaughton (2004)
Ponta do Cabeço foliated anatectic Granite	868 ± 330 (li)#				Silva et al. (2002c)
Syn-collisional magmatism from the southern Domain (RS)					
Pinheiro Machado Suite	609 ± 17		2239	-8.4 ($t=800$)	Silva et al. (1999)
Reworked (migmatitised) basement remnants from the northern domain of Pelotas Orogen (SC)					
Inherited core population from the Águas Mornas banded anatectic granite	2175 ± 13				Silva et al. (2003b)
Camboriú granitic migmatitic complex					
Inherited core population from the Caseca quarry banded anatectic granite	2006 ± 3				Silva and McNaughton (2004)

Table 2 (Continued)

Dated unit	Crystallisation age (Ma)	Metamorphic overprinting age (Ma)	Model T_{DM} age (Ma)	$\epsilon_{Nd}(t)$	Reference
Inherited core population from the Ponta do Cabeço foliated anatectic granite	2174 ± 22				Silva et al. (2002c)
Amphibolite from the Caseca quarry	2167 ± 20				Silva et al. (2000b)
Northern basement of Dom Feliciano Orogen (SC)					
Presidente Nereu Tonalite basement window	2201 ± 7		3022	-7.76 ($t=2200$)	Silva et al. (2000b)
Reworked basement remnants from southern domain of Dom Feliciano Orogen (SC)					
Arroio dos Ratos Gneiss Tonalite	>2000	631 ± 13	2062	+2 ($t=2000$)	Silva et al. (1999)
System of orogens Brasileiro I					
Cryogenian tonalitic gneisses within the ca. 610 Ma syn-collisional granitoids from the Pelotas Orogen					
Tonalitic xenoliths	781 ± 5				Silva et al. (1999)

Acronyms BA, ES, MG, RJ, RS, SC stand for: Bahia, Espírito Santo, Minas Gerais, Rio de Janeiro, Rio Grande do Sul and Santa Catarina States. #: low precise minimum ages obtained on thin, high-U rims; (li): lower intercept; M₁: 1st metamorphic recrystallisation; M₂: 2nd metamorphic recrystallisation. Age based on a single concordant analysis, with precision of (1 σ). With exception of four samples signalized with (*) dated by convention U–Pb systematics (at the CPGeo-IG.USP) and one (**) dated by Pb–Pb evaporation, all the others crystallisation and overprinting ages are zircon U–Pb SHRIMP results. (*) Data obtained.

terrane' and younger (ca. 600 Ma) 'reactivated basement terrane'. Finally, Caby (1998) presented a threefold subdivision for the Pan-African tectono-metamorphic events, in northern Africa: an Early Pan-African tectonic-metamorphic 'Event' (750–700 Ma); a Main Pan-African 'Episode' (630–580 Ma); and a Late Pan-African 'Episode' (580–520 Ma).

The lack of an integrated analysis and the scarcity of robust, zircon-based ages blurred the diachronic evolution, and hindered a fully exploration of their peculiarities in the Brazilian literature. In the central domain of the province, Figueiredo and Campos Neto (1993), and Campos Neto and Figueiredo (1995) discriminated for the first time in the "Costeiro Domain" of the Rio de Janeiro State, an earlier "Brasiliano I Orogeny" (670–600 Ma), i.e. the Ribeira "Belt", and a later "Rio Doce Orogeny" (590–490 Ma). The authors characterised the "Brasiliano I Orogen" on the basis of its major ca. 630 Ma thrust-related granitoid phase, interpreted as a pre-collisional component, succeeded by widespread ca. 590 Ma, post-collisional granitic magmatism. The late development of a pre-collisional stage at ca. 590 Ma, post-dating by approximately 40 m.y. the main tectonic phase recorded in the "Brasiliano I Orogeny" (Table 1), supported the recognition of the younger, "Rio Doce Orogeny". In southern Brazil, there are also references to an E–W temporal orogenic polarity (e.g. Fragoso-César, 1991; Basei et al., 2000).

More recently, Trouw et al. (2000) also proposed a threefold subdivision for the central MPV in three 'stages' (Table 1). The oldest stage (670–600 Ma) was related to the evolution of the Tocantins Province (Brasília Belt) ascribed to the E–W closure of the so-called Brazilides Ocean, west of the São Francisco Craton. The second "stage" (630–520 Ma) developed in response to the closure of the "Ribeira extension of the Adamastor Ocean", whereas the youngest 'stage' (520–480 Ma) represents the Búzios Orogeny from Schmitt (2000).

The present integration of the new U–Pb SHRIMP data (Table 2) and the compiled conventional U–Pb data highlights the 'episodicity' in the orogenic evolution and extinction of orogenic collages, as noted in other Precambrian and Phanerozoic areas (Sengör, 1990). It reinforces the assumption of the superposition or diachronic evolution of orogens with similar timing and significance, as previously characterised in northern Africa (Caby, 1998). Accordingly, a sub-division of the Brasiliano collage into three systems of orogens is delineated (Brasiliano I, II, and III). Each one of these systems is characterised by distinct orogenic paroxysms (collisional peak), precisely dated at ca. 790 Ma and 730–700 Ma (Brasiliano I); ca. 640–620 Ma and ca. 600 Ma (Brasiliano II) and, ca. 595–560 Ma and 520–500 Ma (Brasiliano III) (Table 3; Fig. 3). They have counterparts presenting

Table 3
U–Pb zircon-based tectonic-magmatic repartition of the granitic magmatism from the Mantiqueira Province

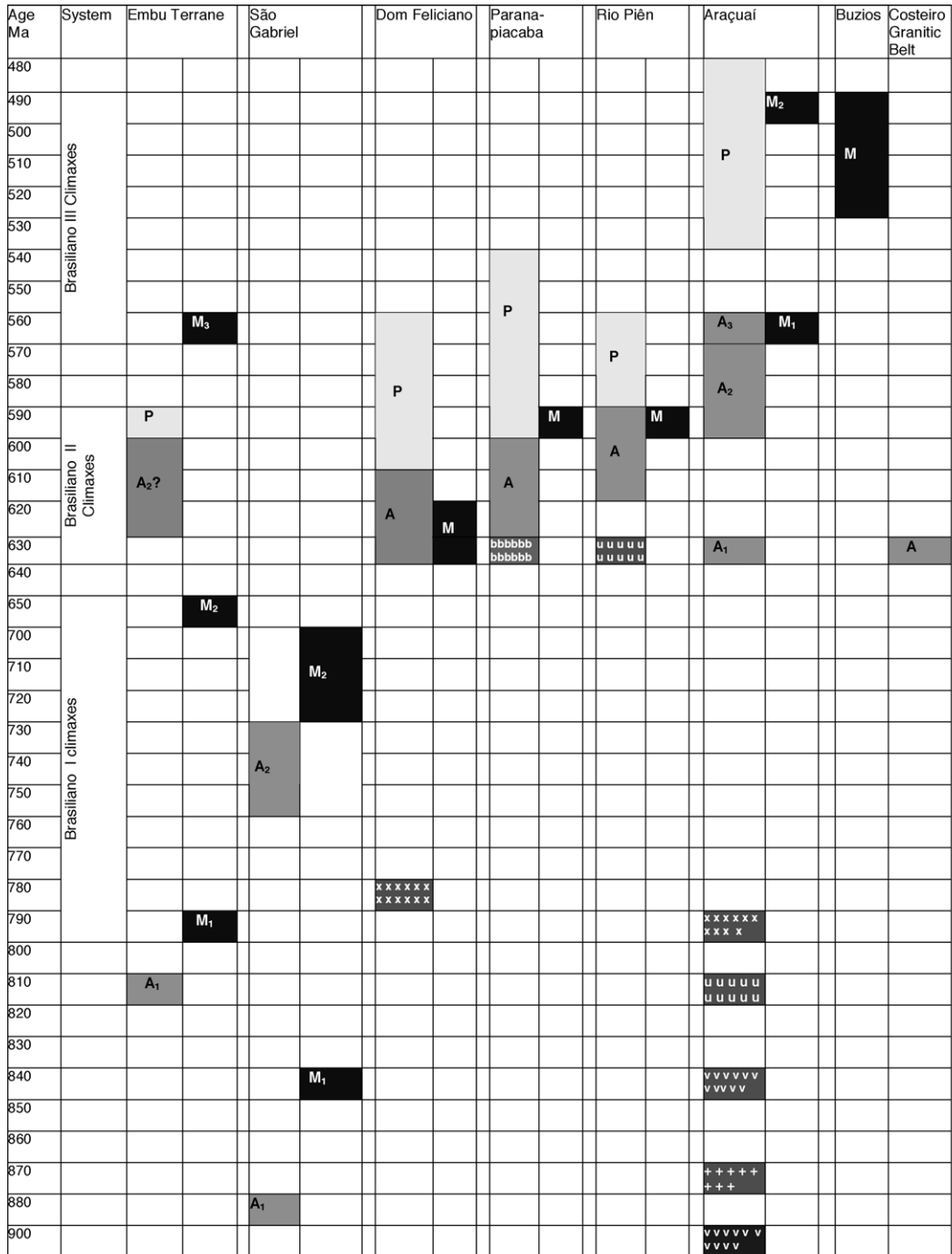
SYSTEMS OF OROGENS	TECTONIC SETTING	MAIN MAGMATIC PULSES (Ma)	DATED GRANITIC PLUTONS (local designations)
BÚZIOS OROGEN			
	Syn-collisional	530-500	S- and I-type syn-collisional migmatitic veins
ARAÇUAÍ OROGEN			
BRASILIANO III	Post-collisional	560-490	Mangaratiba, Aimorés Suite (Padre Paraíso (Charnockite), Caladão, Santa Angélica, Malacacheta, Favela, Pedra Branca, Younger facies from the Nanuque Batholith, Younger facies from the Muniz Freire Batholith, Getulândia, Nova Friburgo
	Syn-collisional	580-560	Pão de Açúcar, Niterói, Corcovado, Garnet granite intrusive into the Rio Negro tonalite, Leucogneiss from Cantagalo town, Nanuque, Guarapari, Alegre, Rio Turvo, Taquaral, Graminha, Estrela, Matias Barbosa (Charnockite), Urucum, Taquaral, S-type neossomes, S-type diatexites, Wolf, Manhauçu, Governador Valadares I, Governador Valadares II
	Pre-collisional	630-570	Rio Negro, Chapada Bueno, Serra dos Órgãos, Muniz Freire, Galiléia, Ataléia, Brasilândia, São Vítor (Teófilo Otoni), Guarataia
BRASILIANO II	DOM FELICIANO, RIO PIÊN, PARANAÍACABA OROGENS AND COSTEIRO GRANITIC BELT		
	Late- to post-Collisional	600-560	São Sepé, Lavras, Lavras Monzonite, Tuna, Arroio do Jaques, Capão do Leão, Bela Vista, Jaguarí Santana, Encruzilhada Arroio Moinho, Piquiri, Arroio do Silva, Tabuleiro, Guabiruba, Santa Luzia, Valsunga II, Subida, Agudos do Sul, Corupá, Morro Redondo, Graciosa, Campo Alegre-Guaratubinha, Serra do Lopo, Serra da Batéia, Apiaí, Piedade, Morro Grande, Saival, Cerne, Palermo, Rio Negro
BRASILIANO I	Pre- to syn-Collisional	640-600	Cañas, Pinheiro Machado; Figueiras, Cerro Agudo, Cordilheira, Francisquinho, Quitéria, Paulo Lopes, Santo Amaro da Imperatriz, Valsungana, Fernandes, Rolador, Major Gercino, Camború Complex anatectic granite, Águas Mornas Complex anatectic granodiorite, Quatro Ilhas, Mariscal, Estaleiro, Piên-Manditiuba, Paranaguá, Apiaí (metagabbro), Apiaí (Granite), Três Córregos Saival, Agudos Grande, Arrieros, Apiaí, Apiaí (Rhyolite), Bragança Paulista, Itaqui, Cantareira (facies Pirituba), Rio turvo, Tico-Tico, Itapeúna, Duas Barras, Pinhal-Ipiúna, Serra Preta, Agudos Grande, São Sebastião, Pirai do Sul, Ribeirão do Butiá, Saival, Sete Barras, Juquiá, Paranaguá
	SÃO GABRIEL OROGEN		
	Volcanic Arc	760-700	Campestre Tuffs
BRASILIANO I	Plutonic Arc/Ophiolite	750-730	Cambaí Complex metatronghemite, metatonalite, Vacacaí metandesiten Cerro Mantiqueira metabasalt
		880	Passinho Metadiorite
EMBU TERRANE			
	Pre-collisional	810	São Lourenço da Serra Arc
ISOLATED CRYOGENIAN TONALITIC GNEISSES			
	?	790-780	Remnants of tonalitic gneisses within the Dom Feliciano and Araçuaí orogens

similar paroxysmal timing in the adjacent western Tocantins Province (southern Brasília Belt) and in the Pan-African orogens (Table 4). The temporally equivalent Pan-African orogenic stages (collage) are, respec-

tively, the Early Pan-African tectonic-metamorphic 'Event'; the Main Pan-African 'Episode', and the Late Pan-African 'Episode' from Caby (1998) (discussed below).

Table 4
Tectonic-magmatic subdivision for the Pan-African systems of orogens

Belt/Orogen	Dated event	Age (Ma)	References
Late Pan-African/Pan-African III (climaxes at ca. 590–540 Ma)			
Saldania Belt	D ₁ /syn-collisional granitoids	550–540	Silva et al. (2000a)
West Congo Belt	D ₁	565	Tack and Fernandes-Alonso (1998)
Kaoko Belt	D ₂ /D ₃ syn-collisional granites	550	Seth et al. (1998)
Sri Lanka	D ₁ /syn-collisional granulites	~550	Kröner et al. (1994, 2001)
Southern India	D ₁ high-grade metamorphic peak	~550	Bartelett et al. (1998), Kröner et al. (2001)
East Atarctica	D ₁ high-grade metamorphic peak and syn-collisional granitoids	M ₂ 530–515 M ₁ 570–550	Jacobs et al. (1998)
Damara Belt			
Central and North branches	D ₂ /D ₃ syn-collisional granitoids	580–560	Porada (1989), Hofmann (1994)
South Branch	D ₁	550	Porada (1989)
Mozambique Belt Tanzania	D ₁	550	Meert et al. (1995)
Mozambique Belt, S Malawi	D ₁ metamorphic peak Calc-alkaline granitoids intrusion	570–550 700–500	Kröner et al. (2001)
Ross Orogeny (Antarctica)	D ₁	540	Rozendaal et al. (1999)
Delamarian Orogeny/Ellsworth-Whitmore Mountains Terrane (Australia)	D ₁	540	Rozendaal et al. (1999)
Pan-African II (climaxes at ca. 650–590 Ma)			
Mozambique Belt E and S Tanzania	D ₁ metamorphic granulitic peak	640–625	Muhongo et al. (2001), Möeller et al. (2000)
Central Madagascar	Pre-collisional gneissic granitoids D ₁ syn-collisional stratoids granites and gabbroic intrusions	800–630 D ₂ 530–515 D ₁ 630–615	Collins et al. (2003) Kröner et al. (2001)
Damara Belt Intracratonic Branch	D ₁ syn-collisional granitoids	650	Frimmel and Frank (1998)
West African Ghana-Togo-Benin Province	D ₁ syn-collisional anatexites and anatexis and charnockite intrusion Eclogites protoliths	600–800	Castaing et al. (1993)
(Early) Pan-African I (climaxes at ca. 800–650 Ma)			
Arabian-Nubian Shield			
Kenya	D ₁ /syn-collisional granitoids	~830–730	Mosley (1993), Kröner and Cordani (2003)
S and E Ethiopia–Sudan–Eritrea	D ₁ granulite metamorphic peak Pre-collisional TGG	740–710 880–700	Unrug (1996) Teklay et al. (1998)
W Ethiopia	Pre-collisional mainly TGG	850	Berhé (1993)
S Ethiopia	Syn-collisional granitoids		
Egypt	Pre and syn-tectonic arc granitoids Pre-collisional mainly TGG	580–900 880	Kröner and Cordani (2003) Fattah and Rahman (1990)
Mozambique Belt Northern Mozambique	Syntectonic high-grade orthogneiss	800	Kröner and Cordani (2003)
North Cameroon Belts	D ₁ syn-collisional granitoids or- thogneisses	670 800–650	Pinna et al. (1994)
Trans-Saharan Belt (Adrar des Iforas Mobile Belt, Mali-Saudi Arabia)	D ₁ /TTG pre-syn-collisional grani- toids Ophiolite	680–640 720–680	Johnson and Kattan (2001), Black and Liégeois (1993)
Katanga Orogeny/Zambezi Belt/Lufilian Arc (Zimbabwe-Zambia)	D ₁ syn-collisional granitoids	850–820 820	Hanson et al. (1994)



A = pre- to syn-collisional plutonic arc, P= post-collisional magmatism; M = Metamorphic Peak; **x x x x** = Cryogenian arc remnants, **v v v v** = Tonian extensional tholeiitic magmatism; **+** **+** **+** **+** = Tonian extensional bimodal magmatism, **u u u u** = mafic-ultramafic ophiolitic slivers, **b b b b** = E-MORB back arc lavas.

Fig. 3. Brasiliano branched systems of orogens from the Mantiqueira Province.

4. (Early) system of orogens Brasiliano I (collisional climaxes at ca. 790 and 730–700 Ma)

The record of this system is restricted to the southwestern domain of the MPV in Rio Grande do Sul State at the Vila Nova Belt (Chemale, 2000), the São Gabriel Orogeny, sensu Hartmann et al. (2000a) and the Embu Terrane (sensu Campos Neto, 2000; Cordani et al., 2002) (Figs. 1, 2a, b and 3).

4.1. São Gabriel Orogen (climax at 730–700 Ma)

The unit constitutes the western domain of the Sulrio-grandense Shield, the Vila Nova Belt, in the southern MPV. Owing to the Neoproterozoic/Eopaleozoic and Phanerozoic deposits laid down on its eastern and northern domains, respectively, the exposed area of the orogen is restricted to some 5000 km². The eastern Neoproterozoic/Eopaleozoic (Camaquã) basin was characterised as a post-collisional foreland basin and related alkaline granites from the adjacent Dom Feliciano Orogen (Gresse et al., 1996). A NW-trending transpressive shear zone (Ibaré) marks the southern limit of the terrane, whereas the eastern limit would correspond to a NE-SW fault (Caçapava) (Chemale, 2000) (Fig. 2a). South of the NW-trending shear zone boundary (Ibaré), in addition to the foreland deposits and associated granitoids, fragments of Archean TTG high-grade gneisses, ascribed to the Rio de La Plata Craton/Plate are also exposed.

The exposed fraction of the orogen comprises remnants of a volcanic-plutonic arc, possible ophiolitic fragments and a back arc basin (discussed below).

4.1.1. Pre-orogenic units (? 900–800 Ma)

Pre-orogenic units include remnants of metamafic-ultramafic plutonic and volcanic assemblages, interleaved with the plutonic and volcanic arc. The mafic-ultramafic slivers are interpreted as scattered remnants of a supposed obducted ophiolite (e.g. Fragoso-César, 1991; Fernandes et al., 1992; Leite et al., 1998). The unit comprises serpentinitised harzburgites, magnesian schists, and amphibolites with tholeiitic affinity intruded by the plutonic arc granitoids (Cerro Mantiqueira unit). Other occurrences of similar assemblages, interleaved with the volcanic arc sequence, are also ascribed to the ophiolitic assemblage (Chemale, 2000).

There are no U–Pb data on the plutonic peridotitic association, but (Leite et al., 1998) obtained a crystallisation age of ca. 733 Ma on a late metabasaltic unit. Minor remnants of an early Tonian mafic plutonic (diorite) was also recognised and yielded a crystallisation age of ca. 890 Ma and a metamorphic age of ca. 850 Ma (Leite et al., 1998, Fig. 3), but its tectonic significance is not well established. Nd isotopic data from Chemale (2000) on the mafic-ultramafic assemblage, indicate a juvenile nature (positive ϵ_{Nd} values) and short-live crustal residence (T_{DM} model age of ca. 1000 Ma) for $t = 750$ Ma. The prediction of the existence of a pre-Adamastor oceanic arm, between the western Rio de La Plata Craton and the eastern Kalahari Craton, designated as the Charrua Ocean, was made on the basis of these juvenile Cryogenian ophiolitic assemblages by Fragoso-César (1991).

4.1.2. Syn-orogenic magmatism (760–730 Ma)

The syn-orogenic magmatism comprises a succession of plutonic-volcanic arc associations metamorphosed in the amphibolite facies. The volcanic arc (Vacacaí Supergroup) comprises a wide range of volcanic-sedimentary units, namely: intermediate calc-alkaline flows and pyroclastic assemblages, tholeiitic mafic-ultramafic rocks, amphibolites, pillowed metabasalts, magnesian schists, serpentinites, marble, metapelites. Slices of the ophiolitic association tectonically interleaved with the arc are also reported. The calc-alkaline volcanics yielded crystallisation ages of ca. 760 Ma and metamorphic ages of ca. 700 Ma (Machado et al., 1990; Leite et al., 1998; Remus et al., 1999). At least two sub-basins show affinities with back arc and accretionary prism environments.

The plutonic arc (Cambaí Group), in turn, comprises an amphibolite facies calc-alkaline TTG association, with minor interleaved supracrustals and mafic-ultramafic plutonics xenoliths interpreted as ophiolitic remnants. The metatonalitic and metadioritic gneisses yielded crystallisation ages spanning from ca. 750 to 730 Ma, and metamorphic ages of ca. 700 Ma (Leite et al., 1998). Babinski et al. (1996) dated a younger dioritic gneissic phase obtaining a crystallisation of ca. 700 Ma. Slivers of the mafic-ultramafic ophiolitic assemblages are tectonically intercalated and are intruded by the arc granitoids. The Nd isotopic signatures of the plutonic-volcanic arc from intermediate tonalitic and dacitic rocks is characterised by positive

ϵ_{Nd} values (for $t=750$ Ma) and model T_{DM} ages close to 1000 Ma (Babinski et al., 1996; Chemale, 2000), indicating relatively short-lived crustal residence for the magma sources. There is only one K-rich granodioritic pluton associated with the TTG gneisses. It furnished a Nd-model age of 820 Ma and positive ϵ_{Nd} values (Babinski et al., 1996), and is interpreted as a more evolved phase of the arc, but its crystallisation age is not well constrained.

Accordingly, the São Gabriel Orogen currently represents best example of a subduction-related orogen (sensu Sengör, 1990) within the MPV. The (main) orogenic magmatic phases within the accreted arc-terrane, evolved in a subduction-related accretionary setting, related to an intraoceanic environment (Machado et al., 1990; Fragoso-César, 1991; Babinski et al., 1996; Leite et al., 1998; Remus et al., 1999; Chemale, 2000).

4.1.3. The reworked basement

Owing to the possible intraoceanic development, there is only local record of reworked basement rocks within the arc-accretionary complex. These occurrences are exposed within the easternmost ca. 870 Ma back arc sub-basin (Passo Feio unit) (Remus et al., 1998). One of the basement rocks is a tholeiitic amphibolite, with an imprecise Paleoproterozoic age (Hartmann et al., 2000a) and a (quasi) Archean orthogneissic sliver with crystallisation zircon U–Pb SHRIMP age of ca. 2450 Ma and metamorphic overprinting age of ca. 560 Ma (Remus et al., 1996, in: Remus et al., 2000b). The authors ascribed the overprinting age to a metamorphic event synchronous with the intrusion of the adjacent syn-tectonic Caçapava granite, a plutonic unit of uncertain tectonic significance, temporally equivalent to the Araçuaí Orogeny (system Brasileiro III).

Only some 80 km E of the intraoceanic arc, remnants of reworked basement tonalitic and granitic orthogneisses (Encantadas Complex) are recognised. The domain is interpreted as a microcontinental setting for the São Gabriel Orogeny evolution (Chemale, 2000) (Fig. 2a). Tonalitic and granitic orthogneisses record crystallisation ages from ca. 2360 to 2260 Ma and a first metamorphic overprinting age of ca. 2021 Ma (C.C. Porcher, in: Chemale, 2000). The latter author dated another orthogneiss, obtaining similar Paleoproterozoic crystallisation ages and early Brasileiro metamorphic age of ca. 800 Ma.

4.2. Embu Terrane (collisional climax at ca. 790 Ma?)

The Embu Complex is a major tectonic unity in the central segment of the MPV (Figs. 1–3). It is exposed within the eastern São Paulo State (Fig. 2b) and comprises mainly amphibolite facies interleaved ortho and paragneisses, locally bearing metavolcanic succession. The pelitic/psammitic paragneisses show widespread in situ partial melting and granitic generation, giving rise to extended S-type granitic-migmatitic domains. The basement consists of orthogneisses with a crystallisation age of ca. 2000 Ma and Archean heritage (Babinski et al., 2001). The NE-trending terrane is flanked to the south-east by the Costeiro Granitic Belt, by means of an NE-trending shear zone (Cubatão). This shear zone is a segment of the main component of the Paraíba do Sul shear systems, and is interpreted as the surface trace of a major terrane boundary. On the north-eastern flank, another transpressive NE-trending shear zone (Taxaquara) separates the Embu Terrane from the granitoids ascribed to the Paranapiacaba Orogen and from the Mesoproterozoic Serra do Itaberaba basin (Figs. 1 and 2b).

4.2.1. (Early) pre-collisional magmatism (ca. 810 Ma)

In the southern segment of the domain, located some 50 km south-west of São Paulo city, an early Neoproterozoic (Cryogenian) tonalitic gneissic association was recognised, by means of U–Pb SHRIMP dating. The gneiss reveals a crystallisation age of 811 ± 13 (Cordani et al., 2002), whereas an approximate age of a (first) metamorphic overprinting was bracketed between 700 and 650 Ma (M_1). Another estimate for the first metamorphic overprinting (ca. 790 Ma) was obtained by means of a chemical isochron determination on primary monazites (Vlach, 2001). Finally (Cordani et al., 2002) based on Rb–Sr data, also estimated an age of ca. 560 Ma for a second metamorphic overprinting (M_2).

4.2.2. Syn- to post-collisional magmatism (ca. 650–580 Ma)

In addition to the early pre-collisional magmatism, several syn- to post-collisional plutons were recognised within the domain presenting crystallisation ages

from ca. 630 to 590 Ma (Tassinari and Campos Neto, 1988; Passarelli, 2001; Filipov and Janasi, 2001). These span the syn- to post-collisional magmatism and suggest that the Embu Terrane shared a common evolution, relative to the adjacent Paranapiacaba Orogen (see below).

4.3. Juxtaposition and collage of the Brasiliano I orogenic components

The reduced dimensions of the exposed São Gabriel orogenic units make it difficult to reconstruct the regional orogenic evolution. The volcanic arc shows a regional NNE-trending foliation and records kinematics structures pointing to a WSW-directed thrusting over a supposed (concealed) eastern margin of the Rio de La Plata Craton. The west-directed overthrusting of the accreted arc, would have occurred in response to an E-directed subduction of the Tonian Charrua Ocean lithosphere (Chemale, 2000) at ca. 700 Ma, as deduced from the metamorphic ages obtained on the volcanic assemblages (Remus et al., 1999). This early collage stage, pre-dated by some 70 m.y. the collage (collisional peak) of the adjacent Dom Feliciano Orogen, which occurred at ca. 630 Ma (Silva et al., 1999, Table 2).

As far as the Embu Terrane is related, the reconstitution of the orogenic history is a more difficult task because of the scarcity of robust ages on the metamorphic overprinting, and complex field relationships. Some authors (Brito-Neves et al., 1999; Campos Neto, 2000; Vlach, 2001; Cordani et al., 2002) suggest that the Embu Complex constitutes a displaced terrane, attached to the north-east domain of the Ribeira Belt (Paranapiacaba Orogen) during the late Brasiliano collage. Despite its supposed exotic nature, a widespread anatectic granitic production phase with ages spanning from ca. 630 to 590 Ma, suggest that it shared at least a common final tectonic-magmatic evolution with the adjacent Paranapiacaba Orogen, and with the Costeiro Granitic Belt. This common evolution has already been emphasised by Wernick et al. (1993), Töpner (1996, 1997), Dantas et al. (2000), among others. The last mentioned work (Dantas et al., 2000), by means of a Sm–Nd study on the basement of both terranes, suggested that both were derived from similar Paleoproterozoic sources.

4.4. Cryogenian tonalitic gneissic remnants with uncertain tectonic significance

Outside the São Gabriel Orogen and Embu Terrane the Brasiliano I magmatism record is, so far, meagre. It is restricted to minor, ca. 790 Ma tonalitic orthogneisses occurring as remnants within the (650–630 Ma) Dom Feliciano Orogen (Silva et al., 1999, Table 2) and in the ca. 630 Ma Rio Negro Arc, within the south-eastern domain of the Araçuaí Orogen (Heilbron and Machado, 2003). Despite the scant available geological and isotopic data for both occurrences, they are of paramount importance as markers of the onset of the accretion of the early Brasiliano Cryogenian continental crust, outside the São Gabriel and Embu domains.

The former occurrence is exposed about 80 km south-east of the plutonic arc from the São Gabriel Orogen and is characterised as tonalitic gneiss, yielding a crystallisation age of 781 ± 5 Ma. The gneisses occur as disrupted xenoliths, intruded by a syn-collisional granitic phase of the Dom Feliciano Orogen, at ca. 610 Ma (Silva et al., 1999, Table 2), resulting in widespread partial melting and anatexis of the tonalitic xenoliths. The tectonic significance of these remnants relative to the regional evolution of the Dom Feliciano Orogen is still poorly constrained. On one hand, they could represent an eastern, extra-orogen, intracontinental arc phase, temporally associated with the onset of the western São Gabriel Orogeny, lately reworked by the Dom Feliciano Orogeny. On the other hand, they also could be remnants of an eastern, distinct orogen, subsequently severed by the accretion of the Dom Feliciano Orogeny magmatic arc. Independently of its origin, Nd isotopic studies furnished moderately negative ε_{Nd} values and model Nd age of 2240 Ma for $t = 800$ Ma (Silva et al., 1999, Table 2), implying the derivation of the tonalite from continental Paleoproterozoic sources, coeval with the Encantadas gneisses, exposed some 60 km W.

Conventional zircon U–Pb studies by Heilbron and Machado (2003) recognised other Cryogenian tonalitic remnant exposed at a western suburb of Rio de Janeiro city. It is associated with the ca. 630 Ma Rio Negro Arc, and furnished a crystallisation age of 792 ± 12 Ma, whereas the metamorphic overprinting age was 493 ± 6 Ma. The authors do not furnished additional comments on the tectonic meaning and the

geographical distribution of these remnants. The age is approximately coeval with the ca. 810 Ma magmatic arc from the adjacent Embu Terrane. Despite their approximately coeval nature, no evidence of possible links between the evolution of both Cryogenian tonalites were discussed and, in a like manner as the southern occurrence, its regional tectonic significance is still uncertain.

4.5. Tocantins Province connections

The early history of the Brasiliano I is followed in the adjacent Tocantins Province/South Brasília Belt by a similar, but not coeval, evolution (Fig. 2b). The accretion of the Passinho diorites in MPV at ca. 880 Ma, took place simultaneously in the Tocantins Province with the accretionary phase of the Goiás Magmatic Arc (950–750 Ma) (Pimentel and Fuck, 1992; Pimentel et al., 1997, 2000). Nevertheless, the temporal equivalence and the restricted occurrence of the ca. 880 Ma metadiorite in the São Gabriel Orogen does not encourage any further comparison between both domains, otherwise separated by some 2000 km distance. On the other hand, there is a good temporal equivalence between the São Gabriel Orogen arc (760–730 Ma) and the ca. 750 Ma Anápolis-Ituaçu Arc, a late component of the Goiás Magmatic Arc (Pimentel et al., 2000).

When it comes to the Embu Terrane, there is synchronicity between the major accretionary events, despite the distinct scales of the volume of newly accretion crust in both domains. The ca. 810 Ma arc from the Embu Terrane is discretely younger (some 20 m.y.) than a late manifestation of the Goiás Magmatic Arc from the Brasília Belt (Tocantins Province), dated at ca. 830 Ma (Pimentel et al., 2000). The ca. 790 Ma for the M_1 , metamorphic peak on the Embu Terrane (Vlach, 2001) is coeval with the age of the M_1 event from the Goiás Magmatic Arc (Pimentel et al., 2000).

4.6. Brasiliano/Pan-African connections

The Brasiliano/Pan-African I system of orogens correspond (in part) to the “Early Pan-African tectonic-metamorphic Event” of Caby (1998). This early stage of juvenile crustal addition is not recorded in the southwestern African belts (i.e. Saldania, Gariep, Damara, Kaoko and West Congo). By the time the subduction of southern Brazilian Charrua Ocean (giving rise to

the intraoceanic arc complex) was under way in southwestern Africa, the break up and rifting of the Kibaran continental crust, followed by the extrusion of the local branch of the Adamastor Ocean, was just beginning (ca. 750 Ma) (Frimmel and Frank, 1998; Chemale, 2000).

In other areas of the African continent, the Pan-African I accretionary phase developed coevally with the Brasiliano I, with large scale production of Tonian and Cryogenian magmatic arcs (Table 4, and references therein). In the north-eastern and eastern parts of Africa (North Cameroon, Trans-Saharan, Mozambique belt, Katangan Orogeny and the Arabian-Nubian Shield, West African Ghana-Togo-Benin Province), the Pan-African events in response to ocean-floor spreading and consumption were dominated by widespread new crustal TTG growth. The Arabian-Nubian Shield records an earlier (ca. 880–700 Ma) TTG accretionary phase, followed by a later ca. 700–650 Ma collisional peak. The North Cameroon belts record an early accretionary phase with ages spanning from ca. 800 to 700 Ma. The Katangan Orogen/Lufilia Arc, in turn, yielded accretion ages from ca. 950 to 820 Ma and a second accretionary stage at ca. 700 Ma. Finally, within the Mozambique Belt, the high-grade metamorphic peak was dyachronous spanning from ca. 800 Ma (Northern Mozambique) to 640 Ma (E and S. Tanzania) and ca. 550 Ma Tanzania and S Malawi (Table 4).

5. System of orogens Brasiliano II (collisional climaxes at ca. 640–620 Ma and ca. 600 Ma)

The system Brasiliano II is ascribed to three orogens, extending from 35° S, close to Montevideo city, to 22° S, northeast of São Paulo city. The orogens are designated from south to north as Pelotas/Dom Feliciano, Rio Piên and Paranapiacaba (Ribeira Belt) (Figs. 1, 2a, b and 3). Besides the three orogens, the system Brasiliano II also comprises the Costeiro Granitic Belt (Basei et al., 2000).

The orogenic climaxes (ca. 640–620 Ma, and ca. 600 Ma) post-date by ca. 130 and 70 m.y. the climaxes recorded by the orogens from the system Brasiliano I, and pre-dates by ca. 40 m.y. the climax from the Araçuaí Orogen (ca. 560 Ma, Brasiliano III) (Fig. 3).

The evolution of the system took a very distinct course as compared to the orogens evolved during the Brasiliano I. The three distinct orogenic domains

are typically collisional-related orogens, characterised by pre- to syn-collisional magmatism with strong influence of Paleo and Mesoproterozoic enriched lithospheric mantle and crust. Additionally, they show widespread post-orogenic magmatism and foreland basin development, associated with the tectonic collapse of the orogen (Fig. 3; Table 3).

5.1. Dom Feliciano Orogen (climax at ca. 640–620 Ma)

The Dom Feliciano Orogen (Dom Feliciano Belt) extends some 1100 km from Montevideo (Uruguay) to the northeast of Santa Catarina State (Figs. 1 and 2a). The main orogenic component is an eastern magmatic arc (Florianópolis, Pelotas and Aygua), and a western metamorphosed continental margin sequence (Brusque, Porongos and Lavallega units) (Fig. 2a). Most of the orogen limits are concealed by the Phanerozoic Paraná Basin to the west and by the Atlantic Ocean to the east. Hence, the tectonic relationships and its limits with the western Rio de La Plata and Paraná plates are unknown. Only its northern tip, characterised by the NNW-thrusting of the passive margin deposits onto the Luís Alves Microplate, is well established (Basei, 1985, 2000). An extended, transpressive shear belt (Major Gercino-Dorsal de Canguçu-Sierra Ballena) separates a magmatic arc from the continental margin deposits in Santa Catarina, Rio Grande do Sul and Uruguay (Basei et al., 2000) (Figs. 1 and 2a). These authors consider the shear belt as a major terrane suture, separating two supposedly unrelated terranes, the eastern granitic arc and the western thrust and fold belt. In the present work we adopted an alternative interpretation by which the shear zone would represent an intracontinental shear belt, separating two domains (the arc and the thrust fold belt), that evolved during a single orogenic episode (Dom Feliciano Orogen).

In Rio Grande do Sul State, post-collisional (foreland) volcanic-sedimentary deposits and coeval alkaline granites overlapped the thrust and fold belt in the western border. At the north-western tip of the arc, Paleoproterozoic basement inliers are exposed between the arc and the post-tectonic western deposits.

5.1.1. Pre-orogenic units

In Uruguay and Rio Grande do Sul State, the main pre-orogenic unit consists of an extended passive con-

tinental margin (Jost and Bittencourt, 1980). The unit is exposed between the eastern border of the Rio de La Plata Plate and the western border of the magmatic arc (Fig. 2a). The sequence was metamorphosed under greenschist to lower amphibolite facies and deformed during the main collisional phase and docked onto the eastern margin of the Rio de La Plata and Paraná plates (Basei, 1985; Basei et al., 2000). Locally the metasedimentary succession includes interleaved metamafic-ultramafic slices (Jost and Bittencourt, 1980), of uncertain tectonic significance. In addition to the ultramafic bodies, felsic volcanic horizons with a crystallisation age of ca. 780 Ma (C.C. Porcher, in: Chemale, 2000a) are intercalated with the metasedimentary package. The tectonic significance of the felsic volcanism is still open to speculations, but the ca. 780 Ma crystallisation age may be a first estimate for the age of the opening stage for the continental margin basin. Reworked interleaved basement orthogneisses furnished zircon U–Pb SHRIMP metamorphic ages of ca. 630 Ma constraining the inversion and metamorphic peak overprinting age within the Pelotas Batholith. In Santa Catarina State the passive margin basin has records of undated minor ocean floor realms (Silva, 1991). Interleaved anatectic felsic volcanics yield a crystallisation age of ca. 640 Ma (Table 2), which represents a preliminary estimate for the age of the waning stages of the sedimentation: the basin opening age is still undetermined. If future studies confirm this ca. 640 Ma age for the depositional sequence, the data will be in disagreement with almost all previous estimates for the age of sedimentation and volcanism. These current estimate for the basin infilling varies from Paleoproterozoic (Silva, 1991), Mesoproterozoic (Basei, 2000), or even Archean (Hartmann et al., 2000a). A minor segment of the sequence, exposed in the north-eastern tip of the Brusque basin, may be considered as a probable Mesoproterozoic remnant, but there are no good geochronological constraints for this interpretations.

5.1.2. Pre- to syn-collisional magmatism

Pre- to syn-collisional granitoids are the main component of the Pelotas Batholith in Rio Grande do Sul State and Uruguay, whereas in Santa Catarina, the post-collisional granitic magmatism is the main component of the Florianópolis Batholith (Fig. 2a). From the chemical and isotopic points of view, the magmatism is

characterised by the predominance of granites s.s., with a narrow compositional range. They have dominantly high-K calc-alkaline (HKCA) signatures, suggestive of their evolution as a mature continental arc. The crystallisation is bracketed between ca. 640 and 620 Ma (Basei, 1985, 2000; Chemale et al., 1995; Babinski et al., 1997; Silva et al., 1999, 2002c; Silva, 1999). The isotopic signatures point to important Mesoproterozoic crustal inheritance for the magmatism from the north segment of the arc (Mantovani et al., 1987; Basei et al., 2000; Silva, 1999; Table 2). Some plutons, occurring outside the main batholith area, are intrusive into the thrust and fold belt, and show older (Paleoproterozoic and Archean) inheritance (Basei, 2000; Silva, 1999; Table 2).

5.1.3. Post-collisional units

The post-collisional, extensional magmatism is also characterised by abundant high-K calc-alkaline, A-type sub alkaline, alkaline with rare peralkaline and shoshonitic plutons (Bittencourt and Nardi, 1993; Basei, 2000; Basei et al., 2000; Chemale et al., 2003; Silva et al., 2002c, 2003b, 2004; Figs. 2a, b and 3; Table 2). The plutonic events are related to the infilling of the late-tectonic Camaquã and Itajaí basins. The former (Camaquã), is located at the south-western margin of the orogen, covering part of the adjacent São Gabriel Orogen. The latter (Itajaí), is exposed over the adjacent Archean basement (Luís Alves Microplate) (Fig. 2a). Both units were interpreted as foreland basins (Gresse et al., 1996) but their true nature is in debate. The volcanism associated to the basin infilling lasted from ca. 610 Ma (Silva et al., 2002c, Table 2) to ca. 560 Ma (Basei, 2000). In Rio Grande do Sul State, the basin infilling phase lasted until ca. 470 Ma, as deduced from the zircon U–Pb SHRIMP age obtained on a basaltic lava flow (Hartmann et al., 2000a). This later phase may represent a taphrogenic event precursor to the onset of the Phanerozoic Paraná basin infilling.

5.1.4. The reworked basement

In the Rio Grande do Sul State, the Phanerozoic Paraná Basin and the foreland deposits from the Dom Feliciano Orogen cover minor Archean cratonic fragments. They comprise mainly granulite-facies TTG orthogneisses (ca. 2550 Ma) and Paleoproterozoic overprinting age (ca. 2020 Ma) (Hartmann et al., 1999) and are ascribed to the Rio de la Plata Craton. Other

occurrences of reworked basement are situated at the north-western tip of the Pelotas Arc, and are comprised of orthogneisses (Arroio dos Ratos unit) and associated high-grade supracrustals and meta-anorthositic rocks (Fig. 2a). A metatonalitic gneiss yielded a metamorphic (SHRIMP) age of ca. 631 Ma and Sm–Nd model-age of ca. 2000 Ma, indicating Paleoproterozoic crystallisation and Brasiliano reworking (Silva et al., 1999, Table 2). A crystallisation age of ca. 2070 was obtained by means of the U–Pb SHRIMP systematics on associated granodioritic gneiss (J. Leite, in: Chemale, 2000). The Paleoproterozoic ages indicate a temporally equivalence between this complex and the Encantadas gneiss from the basement of the adjacent São Gabriel Orogen (Fig. 2a).

Minor expositions of Paleoproterozoic rocks in Santa Catarina State are restricted to partially melted (migmatized) tonalitic and amphibolitic remnants within the syn-collisional Neoproterozoic anatectic granites and migmatites from the batholith (Fig. 2a). Additionally to this restitic material, two major Paleoproterozoic protolithic sources, with crystallisation ages of 2175 ± 13 Ma and 2006 ± 3 Ma where dated on inherited zircon cores from anatectic syn-collisional granitoids (Silva et al., 2002c, 2004, Table 2). Basei (2000) obtained on one of these anatectic granites, through U–Pb conventional systematics, an age of ca. 600 Ma, interpreted as the crystallisation age. The re-assessment of the sample by means of zircon U–Pb SHRIMP systematics, the ca. 600 Ma age was ascribed to melt-precipitated zircon overgrowths, and interpreted as the (anatectic) crystallisation age of the rock (Silva and McNaughton, 2004, Table 2). Despite these isotopic advances, the geographical distribution of the partially melted migmatitic and their country-rocks remnants are still poorly constrained, demanding additional field and isotopic studies. Another minor Paleoproterozoic gneiss (Presidente Nereu), situated north of the orogen is exposed as a basement window in an area of a few km² and yielded a crystallisation age of 2201 ± 17 Ma (Silva et al., 2000b, Table 2).

In Uruguay, another recently recognized basement domain is exposed in Uruguay on the south-eastern flank of the Dom Feliciano Orogen (Fig. 2a). It comprises migmatitic orthogneiss, dated at ca. 1000 Ma (Preciozzi et al., 1999; Basei, 2000). The authors interpreted the domain as a possible fragment of Kibarian basement from the Pan-African orogens of southern

Africa. The discovery of this paleotectonic unit is significant with respect to correlation between the southern MPV orogens and Gariep/Damara counterparts in southern Africa. The possibility exists that this terrane could be a major continental block, concealed by the Atlantic platform sediments.

5.2. Paranapiacaba Orogen (*climax at ca. 610–600 Ma*)

The NE-trending Paranapiacaba Orogen (Figs. 1 and 2a, b) extends ca. 500 km from south-eastern Paraná State to northeast of São Paulo city. Its maximum wide is reached at the south-western domain (ca. 100 km). The northern tip is bounded to the north-west by the Socorro-Guaxupé nappe terrane (Tocantins Province) and on north-east by the Embu Terrane. On the south-eastern flank the orogen is flanked by Mesoproterozoic Perau-Votuverava volcanic-sedimentary (back arc) assemblages (Basei et al., 2003). On the central-eastern segment, the Curitiba Microplate flanks the orogen by means of an inferred suture zone (Lancinha Shear Zone) (Basei et al., 2000; Campos Neto, 2000). Finally, the Phanerozoic Paraná Basin covers the western and south-western orogen flanks.

5.2.1. Pre-orogenic units

In the south domain of the orogen, pre-orogenic units from the Paranapiacaba Orogen are well exposed. They are characterised by passive continental margin deposits, occurring as irregular remnants separated by large orogenic granitic batholiths (Fig. 2a). The deposition was dominated by carbonate platform successions (Itaiacóca, Lajeado and Água Clara units), deep water turbidites (Votuverava unit) and carbonate-psammitic sequences (Capiru and Setuva units) (Campos Neto, 2000). The last mentioned units are thrust to the south-east over the Curitiba Microplate. There are no geochronological data on this depositional episode.

5.2.2. Pre- to syn-collisional units (*ca. 630–605 Ma*)

Pre-collisional units include metavolcanic-sedimentary sequences and pre- to syn-collisional granitoids (Fig. 2a and b). The former are extensional volcanic-sedimentary rift-like successions, exposed

mainly in the north domain in São Paulo State. They are a volcanic-sedimentary association with limited oceanic floor extrusion, and are interpreted as back arc basins (São Roque Group) (Hackspacker et al., 2000; Juliani et al., 2000; Campos Neto, 2000) (Figs. 2a, b and 3). The oceanic floor spreading occurred at 630–620 Ma, the age of the E-MORB lavas and gabbroic intrusions (Hackspacker et al., 2000). The dating of a felsic sequence, coeval with the gabbroic plutonism, yielded a crystallisation age of ca. 620 Ma (Juliani et al., 2000). The basin magmatism preceded the accretion of the syn-collisional granitic arc by ca. 20 m.y. (discussed below).

The continental margin deposits host the orogenic granitic units, which are distributed alongside the ca. 500 km NE-trending extension of the domain (Fig. 2a and b). It consists mainly of high-K calc-alkaline plutons with chemical and isotopic signatures akin to the mature continental arcs and showing a strong Paleoproterozoic influence (e.g. Gimenez Filho et al., 2000; Janasi et al., 2001). The crystallisation ages are bracketed between ca. 630 and 600 Ma (Töpner, 1996; Gimenez Filho et al., 2000; Prazeres Filho, 2000; Janasi et al., 2001).

The syn-collisional metamorphism of the granitoids and volcanic-sedimentary assemblages achieved low-grade conditions (greenschist facies), but presently there is no geochronological data on this event.

5.2.3. Post-collisional units

Extensional magmatic from ca. 610 to 540 Ma followed the cessation of the main contractional episodes (Figs. 2a, b and 3 and Table 7). This event is ascribed to the waning stages of the orogenic episode that characterises the tectonic collapse of the orogens. The intrusions are mainly high-K calc-alkaline, with A-type and silica-oversaturated alkaline signatures, related to distinct juvenile and reworked Paleo and Mesoproterozoic crustal sources and enriched lithospheric mantle (Janasi and Ulbrich, 1991; Prazeres Filho, 2000; Janasi et al., 2001). Minor juvenile shoshonitic phases are locally recognised in association with post-collisional ca. 590 Ma rapakivi plutons (Wernick, 2000).

In addition to the granitic plutonism, the late-tectonic post-tectonic phase also comprises development of volcanic-sedimentary basins, located at the south-western flank of the orogen and classified as foreland basins by Campos Neto (2000).

5.2.4. Reworked basement

The high-grade, migmatized TTG NE-trending Atuba Complex and associated low-grade passive margin successions, designated as the Curitiba Terrane (Siga, 1995; Harara et al., 1997; Basei et al., 2000; Campos Neto, 2000) is the main basement of the orogen. The terrane is considered by these authors as a Microplate setting for the Neoproterozoic evolution. It is a polycyclic domain showing U–Pb conventional ages of ca. 2160 Ma (Siga, 1995; Harara et al., 1997), interpreted as crystallisation ages. In addition to the early Paleoproterozoic ages, Kaulfuss (2001) obtained ca. 1750 Ma for the crystallisation of units previously attributed to the Atuba Complex.

Only recently, by means of U–Pb SHRIMP systematics, Paleoproterozoic ages as ascribed to a first metamorphic/migmatic event (M_1), and a crystallisation age of ca. 3040 Ma was obtained (Sato et al., 2003). The same study also revealed the Neoproterozoic migmatisation age of ca. 560–590 Ma (M_2).

The terrane is in tectonic contact through transpressive transcurrent shear zones with Mesoproterozoic metavolcanic-sedimentary successions (SW), the Paranapiacaba Orogen (NW), and the Rio Piên Orogen (SSE). The northern tip of the domain is in tectonic contact with the Neoproterozoic granitic/supracrustal belt (Costeiro Granitic Belt) and the Embu Terrane. The Lancinha Shear Zone separates the last mentioned (Embu Terrane) from the Curitiba Microplate (Figs. 1 and 2a, b).

The southern and south-central pre-orogenic volcano-sedimentary sequences from the Paranapiacaba Orogen in Paraná and São Paulo States (Fig. 2b) experienced a polycyclic evolution. The initial stage of basin development began in the Calymnian as indicated by a U–Pb age of ca. 1480 Ma, obtained on paleo sills with amphibolitic composition intercalated into a metavolcanic-sedimentary basin in Paraná State (Basei et al., 2003). In São Paulo State, meta-andesites yielded crystallisation ages of ca. 1400 Ma (Juliani et al., 2000). The basin assemblages record incipient sea floor extrusion as indicated by tholeiitic basaltic lavas and intermediate derivatives characteristic of a back arc environment (Juliani et al., 2000). The evolution of these Mesoproterozoic basins lasted until the end of the Brasiliano collage when they became sites of renewed crustal stretching and infilling. The unit evolved as a polycyclic Mesoproterozoic ‘resurrect’ basin (sensu

Sengör, 1990) which, in Neoproterozoic times, gave rise to the São Roque back arc basins, in response to the Paranapiacaba orogenic evolution (Fig. 2b).

5.3. Rio Piên Orogen (climax at ca. 605–595 Ma)

The third component of the system Brasiliano II is represented by a narrow (ca. 250 km long × 25 km wide), wedge shaped, NE-trending syn- to post-orogenic granitic belt. The belt, interpreted as a subduction-related arc (Basei et al., 2000; Harara, 2001), is overthrust to the south-east onto the Luís Alves Craton/Plate, through the Piên-Tijucas transpressive shear zone, and to the north-west it is flanked by the Curitiba Microplate (Figs. 1 and 2a). Relative to the other major orogens from system Brasiliano II, the Rio Piên collisional peak had a later evolution with a collisional climax dated at ca. 605–595 Ma (Harara et al., 1997; Harara, 2001; Figs. 1, 2a, b and 3; Table 3).

5.3.1. Pre-orogenic units (ca. 630 Ma)

Rio Piên Orogen records the best evidence for the presence of ophiolitic remnants in the central MPV (Fig. 3), consisting of meta-mafic-ultramafic plutonic assemblages (Harara et al., 1997; Harara, 2001). A tholeiitic gabbro from this association was dated by means of zircon U–Pb SHRIMP systematics, yielding a crystallisation age of ca. 630 Ma (Harara, 2001), identical, within error, to the age of the ocean floor remnants from the Paranapiacaba Orogen back arc assemblage.

5.3.2. Pre- to syn-collisional magmatism (ca. 620–600 Ma)

Syn-collisional magmatism from the other two major orogens from the system Brasiliano II, and the syn-collisional plutonism from the Rio Piên Orogen, represent chemical (high-K calc-alkaline) and isotopic signature characteristics of the mature continental arcs, with Paleoproterozoic crustal influence (Harara, 2001). The pre-collisional phase of the Piên-Mandirituba Suite, yielded crystallisation ages of 620–610 Ma, whereas the syn-collisional phase, furnished ages of 605–595 Ma (Harara et al., 1997; Harara, 2001).

5.3.3. Post-collisional units (ca. 600–560 Ma)

The post-collisional plutonism occurs along the main NE-trending Piên-Tijucas Suture Zone (Harara, 2001) (Fig. 2a). It shows chemical alkaline and per

alkaline signatures (Kaul and Cordani, 2000; Harara, 2001) and yielded crystallisation ages from ca. 600 to 560 Ma (Siga, 1995; Basei et al., 2000; Harara, 2001). The coeval volcanic-sedimentary basins are located on the southern Archean basement (Luís Alves Microplate), in Paraná and Santa Catarina States (Fig. 2a).

5.3.4. Reworked basement

The orogen is overthrust onto its south-eastern basement, the Santa Catarina Granulitic Complex (Fig. 2a), which is interpreted a microcontinental plate setting for the orogenic evolution (Basei et al., 2000). The domain comprises chiefly high-grade TTG orthogneisses and plutonic mafic-ultramafic rocks, and is intruded by ca. 2000 Ma granitoids and Neoproterozoic/Cambrian alkaline granites and volcanics, and volcanic-sedimentary foreland basins related to the post-orogenic phase of the Rio Piên Orogen (Basei et al., 2000; Harara, 2001). The gneiss complex exhibits chemical signatures suggesting its evolution as an intraoceanic arc (Figueiredo et al., 1996; Hartmann et al., 2000b). The crystallisation age of the TTG association was a matter of dispute in the literature. Only recently, a trondhjemitic orthogneiss yielded, through zircon U–Pb SHRIMP systematics, the Neoproterozoic crystallisation age (ca. 2710 Ma) and a Paleoproterozoic (ca. 2170 Ma) overprint was demonstrated (Hartmann et al., 2000b). The unit is a cratonic fragment (Luís Alves Microcontinent) relative to the southern Dom Feliciano and to the northern Rio Piên orogens (Basei et al., 2000; Brito-Neves et al., 1999; Campos Neto, 2000). In addition to the intense metamorphic Paleoproterozoic overprinting, the unit also shows minor Neoproterozoic reworking. This later episode is restricted mainly to transtensional deformation, associated to post-tectonic, taphrogenic extra-orogen rifting, basin filling, and alkaline magmatism at ca. 600–560 Ma (Siga, 1995; Basei et al., 2000).

5.4. Costeiro Granitic Belt (climax at ca. 615 Ma)

The Costeiro Granitic Belt (sensu Basei et al., 2000) is a narrow (up to 30 km wide) and extended (ca. 100 km long) NE-trending belt, comprising a great diversity of calc-alkaline metagranitic and orthogneissic plutons, as well as remnants of amphibolite facies supracrustal sequences.

The belt is bounded to the south-east by the Archean Luís Alves cratonic fragment, separated by the Costeiro Transcurrent Shear Zone, interpreted a major suture (Basei, 2000). The north-eastern domain of the belt, located between the Atlantic Ocean coast and the Embu Terrane, is in tectonic contact with the latter through the transpressive Cubatão Shear Zone, another supposedly major terrane boundary. In both domains, the granitic belt is overthrust to the north-west onto the Luís Alves Craton and onto the Embu Terrane (Figs. 1 and 2a, b). There are few radiometric ages from the unit, the pre- to syn-collisional calc-alkaline batholiths (Paranaguá) yielded a crystallisation age of ca. 615 Ma (Basei, 2000).

5.5. Juxtaposition and collage of the Brasiliano II orogenic components

As far as the orogenic polarities are referred, there is not a consensus on the evolution of the system Brasiliano II. Within the Dom Feliciano Orogen, the extrusion vector of the collisional structures (flat-lying W-NW-vergent foliation) and the apparent eastward zonation of the post-collisional granitoids, led Campos Neto (2000) and Basei et al. (2000) to postulate an E-dipping subduction of the Adamastor Ocean lithosphere underneath the Kalahari Craton. This polarity pattern is in disagreement with models adopted in most previous works, which inferred a westward subduction of the Kalahari plate under the Rio de La Plata Craton/Plate (e.g. Porada, 1979, 1989; Fragoso-César, 1991; Fernandes et al., 1992; Chemale, 2000, among others).

The Paranapiacaba Orogen (sensu Campos Neto, 2000) also represents a complicated and poorly constrained jig-saw comprising: (i) two evolved continental arc granitoids accreted onto the western margin of the Curitiba Microplate; (ii) two pre-Neoproterozoic terranes (Curitiba and Luís Alves microplates); (iii) Mesoproterozoic and Neoproterozoic resurrected basins (Açungui Supergroup and Serra do Itaberaba Group); and (iv) late- and post-collisional volcano-sedimentary basins. Scenarios for modelling this intricate orogenic evolution may be found elsewhere (Hackspacker et al., 2000; Campos Neto, 2000), but a generalised model of orogenic juxtaposition for this complicated jig-saw is, so far, incomplete and mostly speculative, deserving

more additional systematic isotopic and structural studies.

The Rio Piên Orogen/arc (Figs. 1 and 2a), in turn, represents a narrow wedge shaped unit, comprising a syn-orogenic calc-alkaline suite (Piên-Mandirituba Arc) ascribed to a NW-directed subduction of a local arm of the Adamastor Ocean (Machiavelli et al., 1993; Basei et al., 2000; Harara, 2001). The south-eastern flank of the arc is overthrust to the SE onto its basement (Luís Alves Microplate), by means of a transpressive shear zone. This tectonic limit would correspond to a major Neoproterozoic suture, the so-called Piên Suture Zone (Basei et al., 2000; Harara, 2001).

5.6. Tocantins Province connections

The system Brasiliano II followed a similar evolution in the adjacent Southern Brasília Belt from the Tocantins Province, with a coeval collisional climax M_1 at ca. 630 Ma within the Socorro-Guaxupé Nappe/Orogen. This event, resulting from the westward subduction of the São Francisco Plate under the Paraná Plate, corresponds to the “first orogenic stage” (Trouw et al., 2000; Campos Neto, 2000). Subsequently, this Nappe system was overprinted by the westward collage of the Araçuaí Orogen, against the southern margin of the São Francisco Plate, at ca. 560 Ma (Trouw et al., 2000; Fig. 2a). This “second orogenic stage” (M_2), resulting from the subduction southern margin of the São Francisco plate under the Araçuaí Orogen arc, caused a complex interference pattern on the nappe system with a late NW-direct tectonic transport (Trouw et al., 2000; Fig. 2b).

5.7. Pan-African connections

The Brasiliano/Pan-African II system of orogens broadly corresponds to the “Main Pan-African Episode” from Caby (1998). The temporal equivalence between the Brasiliano II system of orogens and the Pan-African II includes mainly the West African Ghana-Togo-Benin Province; the Mozambique Belt closure at the S and W Tanzania; the intracratonic branch of the Damara Belt; the D_1 metamorphic peak at the Central Madagascar orogens, and to the second collisional stage within the North Cameroon belts (Table 4, and references therein).

A broad correlation between the south-western Pan-African orogens, i.e. Damara, Saldania, Gariep and Kaoko belts, and the southern Brazilian Dom Feliciano, Paranapiacaba and Rio Piên orogens (Brasiliano II), has long been accepted (e.g. Porada, 1979, 1989; Fragoso-César 1991; Trompette, 1994; Gresse et al., 1996, among others). Despite this consensus, new U–Pb ages obtained on the Saldanian syn-collisional granitoids of ca. 550 Ma (Silva et al., 2000a, Table 2) and of ca. 565 Ma on the Kaoko Belt granitoids furnished new insight to the debate. Ages from the Pan-African collisional magmatism, some 70 m.y. younger than their Brazilian counterparts led (Silva et al., 1997a, 2000a; Frimmel and Frank, 1998) to argue against the current correlation models.

6. Brasiliano III system of orogens (climaxes at 595–560 Ma and 530–500 Ma)

This later orogenic system embraces the Araçuaí Orogen (collisional climax at 595–560 Ma) and the youngest collisional event within the province, ascribed to the 530–500 Ma Búzios Orogeny (Figs. 1 and 2b; Table 2, and references therein).

The Araçuaí Orogen embraces the entire northern domain of the province from southern Bahia State to the vicinities of the Rio de Janeiro city, some 950 km south (Figs. 1 and 2b). A large pre- to syn-collisional granitic belt, hosted into huge metamorphosed metasedimentary and volcanic-sedimentary successions (thrust and fold belt), are the main orogenic units. On its western and northern tectonic domains, the orogen is bounded by the reworked Archean/Paleoproterozoic cratonic margin of the São Francisco Craton, whereas to the east, it is concealed by the Atlantic Ocean platform. The manner in which the Araçuaí Orogen terminated to the south remains unresolved as its southern connections with the Ribeira Belt units are poorly defined. Some authors are very cautious about the presence of the orogen south of the 21° S parallel and are inclined to use this parallel reference as the Araçuaí-Ribeira boundary (e.g. Wiedmann-Leonardos et al., 2000). The inflection to NNE of the regional NE-trending direction of the southernmost segment (in the vicinity of the 21° S parallel) may have some influence on the establishment of this limit. Despite these opinions, we consider the southern tip of the ca. 590–560 Ma granitic

belt, the south-eastern termination of the orogen, to be located in the vicinity of the Rio de Janeiro city, more than 200 km southern of the reference parallel (Figs. 1 and 2a). Accordingly, this configuration for the Araçuaí Orogen embraces at its southern boundary, the Rio Doce and Rio Negro orogens from Figueiredo and Campos Neto (1993) and Campos Neto (2000).

Outside the Araçuaí Belt, in Rio Grande do Sul State, an isolated minor (40 km × 10 km) syn-tectonic granitic intrusion (Caçapava do Sul Batholith), geographically associated to the Dom Feliciano Orogen, was dated at ca. 560 Ma (Remus et al., 2000a). The same age (ca. 560 Ma) was obtained on the reworked ca. 2450 Ma basement of the syn-orogen pluton (Remus et al., 1996, in: Remus et al., 1999). Both ages suggest a local event developed temporally with the Araçuaí Orogen collisional peak. Owing to the small exposed area, it is not possible to evaluate the regional significance and the orogenic context from these units.

6.1. Pre-orogenic units from the Araçuaí Orogen (?1000–840 Ma)

The orogen is characterised by a large continental margin depositional assemblage represented by the Macaúbas Group and correlatives, laid down in the north-western (external) domain (Fig. 2b). There are few isotopic data to place constraints on the sedimentation age of the continental margin associations but at the northwesternmost extremity, the association includes extensive record of pre-Sturtian (?) glacio-marine metadiamicrites. The maximum age for the depositional phase obtained on detrital zircon is ca. 950 Ma (Pedrosa-Soares and Wiedmann-Leonardos, 2000).

Some 50 km south-east of the glacio-marine (proximal) deposit, the continental margin succession shows a record of an ocean formation stage comprising distal, deep sea deposits (Ribeirão da Folha unit), containing mafic-ultramafic plutonics, tholeiitic amphibolites, pelitic and chemical-exhalative rocks, interpreted as dispersed and metamorphosed oceanic floor and ophiolitic remnants (Pedrosa-Soares et al., 1998). One of the amphibolitic occurrences was dated (whole-rock Sm–Nd isochron systematics) and furnished an apparent age of ca. 820 Ma, interpreted by the authors, as the extrusion age of the oceanic floor realms.

Marine metasedimentary and metavolcanic-sedimentary successions are also the dominant units at the eastern (internal) domain of the orogen (Rio Doce, Paraíba do Sul groups and correlatives) (Fig. 2a). They are poorly constrained from the depositional point of view, owing to metamorphic overprinting under higher conditions (amphibolite and granulite). Accordingly, their internal organisation, depositional environments, and the timing relatively to the basins and orogenic evolution, are not well established. Consequently, some of these successions may correspond to pre- and syn-orogenic sub-basins, whereas others, to passive margins. Oceanic successions, like those described by Pedrosa-Soares et al. (1998) at the NW segment, seem to be absent from the eastern (internal domain). At the southeasternmost extension of the internal domain, MORB-type amphibolites interleaved with the marine succession were recognised, and yielded a (conventional U–Pb) crystallisation age of ca. 850 Ma (Heilbron and Machado, 2003). The dated amphibolites were interpreted by the authors as syn-depositional dykes constraining the maximum age limit for the basin infilling.

The onset of the break-up of the continental crust, precursor to the rifting and drifting phase, was only recently recognised through the dating of a felsic-alkaline bimodal pluton, intrusive into the basement of the northern tip of the orogen (Salto da Divisa foliated granite). The pluton, affected by the Araçuaí main deformation phase, yielded a magmatic zircon U–Pb SHRIMP crystallisation age of 875 ± 9 Ma (Silva et al., 2002a, Table 2). In the western basement of the orogen some mafic tholeiitic dykes, with crystallisation ages of ca. 900 Ma is another indirect estimate for the age of the extensional pre-orogenic stage (Machado et al., 1989). Finally, an alkaline intrusion into the northern cratonic basement, dated at ca. 675 Ma (Teixeira et al., 1997), is the youngest record of the extensional pre-orogenic magmatism.

6.2. (Early) pre-collisional magmatism (ca. 630 Ma)

The pre-collisional (ca. 630 Ma) magmatic phase of the orogen is represented by two tonalitic gneissic complexes. The main unit is exposed at the southernmost segment of the orogen (Serra do Mar Microplate of Campos Neto, 2000), in Rio de Janeiro

State (Rio Negro Complex). Some 600 km north-east of this major complex, in Minas Gerais State, another coeval tonalitic association (Chapada Bueno Tonalitic Gneiss), still poorly constrained from the cartographical point of view, crops out.

The former (main) association, is exposed as a long (ca. 200 km long) and very narrow (ca. 3 km wide) terrane comprising an expanded (*sensu* Pitcher, 1983) dioritic to granodioritic, mainly tonalitic gneissic association (Tupinambá, 1999; Tupinambá et al., 2000). The unit is intruded and locally severed by a late pre-collisional phase (Serra dos Órgãos unit) intruded at ca. 570 Ma (Silva et al., 2003a, Table 2). A tonalitic gneiss from the complex yielded a U–Pb conventional zircon age of ca. 634 Ma, interpreted as the crystallisation age of the pluton (Tupinambá et al., 2000). Based on isotopic (Nd and Sr) data, the unit was ascribed to a juvenile intraoceanic pre-collisional magmatic arc (Tupinambá, 1999; Tupinambá et al., 2000; Heilbron and Machado, 2003). In addition to the juvenile, dominant tonalitic association, the arc also includes S-type leucogranites and gneisses, dated at ca. 600 Ma (Tupinambá et al., 2000).

Besides this major exposition, other remnants of coeval tonalitic gneiss (Chapada Bueno Tonalitic Gneiss) are known further north, in Minas Gerais State (Paes, 1999). A tonalitic gneiss from this unit, was dated through Pb–Pb evaporation and U–Pb conventional methods and yielded respectively ca. 625 Ma (Paes, 1999) and 630 Ma (L.C. Silva, unpublished data, Table 2). In a like manner as that observed in the Rio Negro Arc, the tonalitic gneiss is also intruded by a later pre-collisional association (Galiléia Tonalite), dated at ca. 590 Ma (Nalini, 1997). Presently, we are unable to judge whether the northern early tonalitic occurrence has a direct geotectonic relation to the Rio Negro Arc, or whether it represents a distinct tectonic unit. Nevertheless, these uncertainties and the recognition of this coeval tonalitic association further north highlights the importance of the earlier pre-collisional magmatism within the Araçuaí Orogen evolution.

6.3. Pre-to syn-collisional units (580–560 Ma)

A discontinuous 900 km long NNE-trending granitic belt, hosted into the pre- and syn-orogenic metasedimentary belt, represents the pre- to syn-collisional plutonic stage (Fig. 2b). The belt is composed of a great

quantity of isolated plutons and major batholiths, which do not define a continuum, but are internally organised according to major E–W compositional zoning (Fig. 3; Tables 2 and 3). The western plutons comprise mainly pre- to syn-collisional, high-K calc-alkaline continental arc-association, whereas the easternmost plutons are composed mainly of S-type anatectic granites typical of a syn-collisional continental arc-associations.

The former (western arc) includes three major batholiths (Serra dos Órgãos, Moniz Freire and Galiléia) characterised by discrete post-magmatic solid-state metamorphic overprinting. The crystallisation ages record a North–South age-span from ca. 595 to 585 Ma (Galiléia Batholith); ca. 580 Ma (Moniz Freire Batholith), and ca. 570 Ma (Serra dos Órgãos Batholith) (Söllner et al., 1989; Nalini, 1997; Tupinambá, 1999; Noce et al., 2000; Silva et al., 2003a). They represent chemical and isotopic affinities with the Cordilleran I-type, K-rich calc-alkaline series (*sensu* Pitcher, 1983). Their Nd isotopic signature is akin to the mature continental arcs, with contribution from enriched Paleoproterozoic mantle lithosphere and crustal sources (Nalini, 1997; Tupinambá, 1999). Accordingly, the extended association corresponds to a (late) pre-collisional phase from the Araçuaí Orogen (Serra dos Órgãos–Galiléia Arc).

The latter (eastern arc) is composed of numerous (discontinuously exposed) syn-collisional peraluminous leucogranitic/charnockitic S-type plutons, exhibiting moderate to strong solid-state overprinting, and constitute the eastern anatectic association. Peraluminous granitic augengneisses, with chemical and petrographic crustal signatures (S-type gneissic granites) including C-type foliated granites (charnockites), predominate in the south-eastern extension. It is the largest granitic association within the orogen, extending discontinuously from Rio de Janeiro city (Pão de Açúcar and Corcovado hills) for some 900 km north, reaching the limit between Minas Gerais and Bahia States. The syn-collisional crystallisation ages also varies from north to south from ca. 580 Ma (Nanuque Batholith) to ca. 560 Ma (Rio de Janeiro Batholith) (Silva et al., 2003a, Table 2) and characterises a continentally recycled magmatic arc (Rio de Janeiro–Nanuque).

One of the most striking features, which make the Brasileiro III granitic magmatism unique within the province, is the ubiquitous exposure of orthopyroxene-bearing granitoids (charnockites). Owing to the lack

of detailed studies, and to the ubiquitous presence of orthopyroxene, these charnockites have been mistakenly mapped and associated with the Paleoproterozoic Juiz de Fora orthogranulitic basement, which precluded their correct presentation on the available maps. Only in recent works has their magmatic nature and Neoproterozoic age been recognised (Jord-Evangelista, 1996; Duarte, 1998; Silva et al., 2000c). At least the garnet-free members of these associations show affinities with the magmatic (anatectic) charnockites, and the C-type granitoids from Killpatrick and Ellis (1992) and Young et al. (1997). One pluton, from the garnet-charnockitic association yielded a zircon U–Pb SHRIMP crystallisation age of ca. 580 Ma (Silva et al., 2002a, Table 2).

In addition to the orogenic magmatism, the pre-collisional stage of the orogen also records flysh-like, deep sea, metaturbiditic deposits, associated with the continental margin deposits. The internal organisation of these assemblages is not well defined, accordingly their relations with the orogenic zonation are not defined. At the western external tectonic domain one of the sub-basins (Salinas unit) represents a maximum depositional age of ca. 570 Ma, obtained on detrital zircons, and was ascribed to a late collisional deposition stage and the adjacent arc degradation (Lima et al., 2002). Another sub-basin from the north-western domain (Capelinha Formation) also presents syn-collisional affinities, although there is no available radiometric age (Pedrosa-Soares and Wiedmann-Leonardos, 2000).

The syn-collisional stage culminated with the inversion and metamorphism of rifted basins and is characterised by strong east-west variation in the metamorphic conditions. Low-grade metamorphic continental margin sequences predominate within the western (external) domain. The eastern (internal) domain, in turn, was affected dominantly by amphibolite and granulite facies metamorphism, under and low P–high T (cordierite in/kyanite out).

Pedrosa-Soares et al. (2001) delineated a major internal organisation of the orogen, and highlighted a transversal metamorphic polarity. Within the western (external) tectonic domain, comprising mainly continental margin deposits, metamorphic grade increases from low greenschist to low amphibolite facies from west to east. The eastern (internal) domain, in turn, comprising the magmatic granitic belt and the (anatectic roots) of the metasedimentary and volcanic-

sedimentary marine successions, is characterised by a northern amphibolite-facies sub-domain and a southern granulite-facies sub-domain.

These higher metamorphic conditions gave rise to the abundant ca. 580–560 Ma syn-peak S- and C-type magmatism (Table 2). Accordingly, the eastern sequence represents the roots (core) of the thrust and fold belt system, overthrust onto the eastern margin of the São Francisco Plate. At the north-western tip of the orogen, the metasedimentary belt shows a NNE–SSW-trend inflexion (Fig. 2b) as well as an inverted E-vergent tectonic transport. Accordingly, it represents a possible segment from the opposite continental margin of the Congo Craton (Pedrosa-Soares, personal communication).

6.4. Late- to post-collisional magmatism (ca. 540–480 Ma)

The remaining exposed granitic phases within the orogen (some 10% of the exposed arc) presents compositional variations from gabbros to syenites, with frequent charnockitic phases, and minor scattered, dominantly I-type and alkaline plutons (Wiedemann, 1993; Figueiredo and Campos Neto, 1993; Campos Neto and Figueiredo, 1995; Pedrosa-Soares and Wiedmann-Leonardos, 2000) (Fig. 2b). They represent the final collapse of the orogen and crop out as occasionally zoned small batholiths, with mafic cores (Wiedemann, 1993; Pedrosa-Soares and Wiedmann-Leonardos, 2000). The tholeiitic phases present contaminated mantle signatures, when compared to the modern arc-tholeiitic series. The high-K felsic magmatism has been explained in terms of a chemical and isotopically “atypical” intracontinental arc (Wiedemann, 1993). The arc was ascribed to the waning stages of the orogen, succeeding an east-directed subduction of an oceanic lithosphere, and continent–continent collision (Wiedemann, 1993). The crystallisation ages of this post-collisional phase range from ca. 540 to 480 Ma (Fig. 3; Tables 2 and 3).

6.5. The reworked basement

The largest segment of Archean rocks reworked by the Brasiliano event within MPV is the north-western segment of the Araçuaí Orogen, the Guanhães Complex (Fig. 2a). It comprises chiefly TTG orthogneiss, and has

been interpreted as an alloctonous terrane, incorporated into the craton during the Brasiliano/Araçuaí collage. The SHRIMP results yielded crystallisation ages from ca. 2900 to 2700 Ma, and Neoproterozoic overprinting metamorphic ages (Silva et al., 2002a, Table 2). As the data are compatible with previous ages obtained in the cratonic basement from the south-east domain of the craton (Carneiro et al., 1998; Noce et al., 1998; Teixeira et al., 2000), it is presently reinterpreted as part of the Archean reworked basement of the craton, and not as a displaced terrane, juxtaposed during the Neoproterozoic collage. Together with the adjacent Paleoproterozoic orthogneiss complexes (see below), it corresponds to the western continental margin of the Araçuaí Orogen in Minas Gerais State (Fig. 2b; Table 2).

In Bahia State, the northern tip of the orogen is thrust against a Archean/Paleoproterozoic gneissic basement (Fig. 2b), but there is no reliable geochronological data on this continental margin domain. Only about 150 km north of this limit, a ca. 2710 Ma high-grade charnockitic gneiss shows Neoproterozoic overprinting, characterised by discrete zircon rims (overgrowths), imprecisely dated at ca. 710 Ma (1σ), by SHRIMP systematics (Silva et al., 2002c, Table 2).

In addition to the Archean cratonic margin, Paleoproterozoic orthogneisses constitute most of the reworked south-western basement of the orogen, at the south-easternmost margin of the São Francisco Craton/Plate in Minas Gerais State (Fig. 2b; Table 2). They are severed TTG gneissic associations, interpreted as the roots of an arc accreted onto the eastern margin of the São Francisco Craton/Plate (Silva et al., 2002a). The pre-collisional phase of the TTG arc, presently exposed as amphibolite facies highly transposed mylonitic orthogneisses (Piedade, formerly Mantiqueira Complex), furnished crystallisation ages from ca. 2200 to 2100 Ma. The syn-collisional phase, in turn, was accreted between 2100 and 2050 Ma, the approximate age also of the first metamorphic event (M_1) recorded on the gneiss (Silva et al., 2002a). The metamorphic temperatures operating during the collisional peak were high, and the thermal flux remained elevated after the collisional peak, giving rise to late-collisional crustal melts with charnockitic composition, dated at ca. 2100 Ma (Table 2). The authors interpret these domains as the severed roots of a reworked continental margin arc, coeval with the Paleoproterozoic batholiths intruded into the southern tip of the craton and ascribed to the

Mineiro Belt (Teixeira and Figueiredo, 1991). Together with the adjacent western Archean TTG orthogneisses, they correspond to the easternmost continental margin of the São Francisco Craton/Plate. A second and better constrained metamorphic overprinting (M_2) corresponding to the Neoproterozoic collage of the Araçuaí Orogen onto the eastern São Francisco cratonic margin, yielded an age of ca. 580–570 Ma (Silva et al., 2002a, Table 2).

South-east of this unit, another high-grade orthogneissic domain (Juiz de Fora Complex) corresponding to the easternmost component of the São Francisco Plate, the margin furnished crystallisation ages on a charno-enderbitic gneisses from ca. 2200 to 2140 Ma. The metamorphic granulite-grade overprinting, in turn, yielded ca. 580 Ma (Söllner et al., 1991; Machado et al., 1996).

Another Paleoproterozoic orthogneiss (Caparaó Complex, Fig. 2b) showing Brasiliano granulite-facies overprinting, crops out as a reworked basement inlier at the core of the orogen. A charnockitic leucogneiss furnished ca. 2195 and 590 Ma ages for the crystallisation and metamorphic overprinting events, respectively (Silva et al., 2002a, Table 2). The same unit furnished similar ages through conventional U–Pb analysis, but the crystallisation age was interpreted as the age of the precursor of the rock (Söllner et al., 1991).

North of the Caparaó Complex, in apparent continuity is exposed in an amphibolite facies, reworked basement orthogneissic domain (Pocrane Complex, Fig. 2b). The unity is poorly constrained from the geologic and isotopic points of view, and until now is devoid of radiometric age. Only one amphibolitic paleodyke, intrusive into the regional orthogneiss was dated by means of zircon U–Pb SHRIMP systematics, and furnished a crystallisation age of ca. 1500 Ma and metamorphic overprinting of ca. 600 Ma (Table 2). Accordingly, the 1500 Ma crystallisation age obtained on the paleodyke, represents a minimum age expected for the orthogneissic country-rock.

West of Rio de Janeiro State, another orthogneiss from the basement of the orogen (Quirino Orthogneiss) (Fig. 2b) yielded crystallisation ages of ca. 2185 Ma (Valladares et al., 1996). The role of this minor domain during the orogenic evolution is not clear but the authors also dated a metamorphic overprint yielding ca. 600 Ma.

Besides the orthogneissic units, other remnants of the Paleoproterozoic megacycle are also present, especially the rift-sag Espinhaço basin (Espinhaço Super-group) (Fig. 2b). The basin evolution started at ca. 1700 Ma, as indicated by U–Pb ages obtained on a metarhyolite (Brito-Neves et al., 1979) and on baddeleyite from mafic dykes, interpreted as related to the extension of the basin (Silva et al., 1995). The Borrachudos alkaline metagranite is another Paleoproterozoic remnant of the taphrogenic phase, intrusive into the Archean basement west of the orogen (Fig. 2b). The pluton was deformed and metamorphosed in response to the Brasiliano overprinting on the eastern São Francisco Cratonic margin. The rock presents U–Pb crystallisation ages from ca. 1670 Ma (Chemale et al., 1998) to ca. 1740 Ma (Silva et al., 2002a, Table 2). It also shows evidence of Neoproterozoic (undated) metamorphic overprinting on the rims of the analysed zircon populations (Silva et al., 2002a).

6.6. Juxtaposition and collage of the orogenic components: the Araçuaí Orogen redefined

The precise characterization of these Late Precambrian (ca. 595–560 Ma) pre- and syn-orogenic arcs (Table 2) reinforces the characterisation of a younger orogenic stage predicted on the basis of regional studies on the north-eastern tip of the Ribeira Belt (Serra do Mar Microplate), i.e. the ‘Rio Doce’ Orogeny (Figueiredo and Campos Neto, 1993; Campos Neto, 2000). Owing to the compatible tectono-structural, chemical signatures, and orogenic granitic stages in the Araçuaí Orogen and in the Serra do Mar Microplate, we considered the ‘Rio Doce’ Orogen as a south-eastern extension of the Araçuaí Orogen. Actually, both segments share a common convergent process initiated with the accretion of juvenile intraoceanic arcs at ca. 630 Ma. This initial stage was followed by accretion of the cordilleran continental arc (ca. 595–570 Ma) culminating with widespread syn-collisional anatexis and the dockage of arc-terranes onto the eastern cratonic margin (at ca. 580–560 Ma) (Table 2; Fig. 3). The E-directed subduction of the previously amalgamated São Francisco/Paraná plates (beneath the Serra do Mar Microplate) was the mechanism responsible by this evolutionary process (Pedrosa-Soares et al., 2001; Heilbron and Machado, 2003).

The orogenic evolution of the early intraoceanic Rio Negro and the Araçuaí Orogen is considered elsewhere (Campos Neto, 2000). The author discriminates an early, ca. 630 Ma Rio Negro Arc/Orogen, from the ca. 590 to 560 Ma Rio Doce Orogen (herein interpreted as a south-eastern extension of the Araçuaí Orogen). The recent characterisation of ca. 630 Ma tonalitic gneisses, within the pre-collisional phase of the Araçuaí Orogen (Table 2), and coeval with the Rio Negro Arc, favours a continuous evolution for both associations, as part of a single orogen. Nevertheless, even with the new isotopic constraints there is no robust evidence to place firm constraints on these concurring evolutionary models, and much additional field and isotopic work is needed to clarify the issue.

The assumed age of the ocean floor extrusion of ca. 820 Ma (Pedrosa-Soares et al., 1998) suggests it probably represents a north-east extension of the Tonian Goianides and Charrua oceans, precursors to the Adamastor ocean proper. The former (Goianides), was subducted beneath the south-western margin of the São Francisco Plate (Pimentel et al., 1997; Campos Neto, 2000) and the latter (Charrua), subducted under the eastern margin Rio de La Plata Plate further south (Chemale, 2000).

Recent Sm–Nd isotopic studies on the Araçuaí Orogen granitoids highlighted the role of a Meso to Paleoproterozoic remobilised continental crust, during the Late Brasiliano collision (e.g. Nalini, 1997; Tupinambá, 1999). We interpret these 1600 to 2000 Ma T_{DM} ages in the same context of the evolution of the Southern MPV granitoids, synthesised on Table 2, i.e. as mixed-source magmas, resulting from the melting of a Paleoproterozoic continental crust and lithospheric mantle and mixing with newly accreted, juvenile melts (e.g. Silva, 1999; Cordani et al., 2000).

6.7. Búzios Orogen (collisional climax at 530–500 Ma)

Outside the Araçuaí Orogen, the latest stage of the system Brasiliano III is ascribed to the Búzios Orogeny (Schmitt, 2000). This orogenic event was recognised on the basis of precise dating of “in situ” thrust-related migmatitic veins, associated with the west-vergent thrusting of the Cabo Frio Terrane onto the south-eastern extension of the Araçuaí Orogen, at ca. 530–500 Ma (Schmitt, 2000) (Figs. 2b and 3). A major

component of the Búzios Orogen is an amphibolite facies volcanic-sedimentary rift-like succession, including N-MORB amphibolites and metaturbidites. The amphibolites yielded Sm–Nd model ages of ca. 1000 Ma, whereas detrital zircons from the latter, yielded minimum ages spanning from ca. 1000 to 700 Ma (Schmitt, 2000). Distinct from what is observed in the adjacent Neoproterozoic orogens, the Búzios Orogen collisional climax occurred under medium to high P/T conditions, as deduced from the presence of garnet-amphibolites and kyanite-sillimanite and kyanite-K-feldspar assemblages, in high-grade metapelites (Schmitt, 2000).

The effect of this Cambrian convergent stage was also recognised by means of conventional zircon U–Pb geochronology (Heilbron and Machado, 2003) on gneisses herein interpreted as a major component of the south-eastern tip of the Araçuaí Orogen. This latest Brasiliano collage episode is interpreted as a result of the subduction of a possible promontory of the Congo Plate underneath the already welded south-eastern extension of the Araçuaí Orogen, implying a north-west-directed subduction of the Adamastor Ocean at 530–500 Ma (Schmitt, 2000; Campos Neto, 2000; Heilbron and Machado, 2003).

Other Cambrian compressional magmatic episode related to a generation of syn-tectonic, amphibolite-facies anatectic mobilisates occur within the Mesoproterozoic Punta del Este Terrane (Fig. 2a). It is dated at ca. 540–520 Ma (Preciozzi et al., 1999; Basei et al., 2000). The authors interpret this event as a southern extension of the Rio Doce Orogeny (herein treated as the Araçuaí Orogeny). Owing to the younger 520 Ma age, relative to the 560 Ma age of the Araçuaí collisional peak, we prefer to temporally correlate this event with the ca. 530–500 Ma Búzios Orogen. In addition to the Búzios Orogen, the ca. 540–520 Ma Pampean Orogen (Rapela, 2000), situated about 1000 km south-east in Argentina and Paraguay (Rapela, 2000) took place within the same interval. But in this case, the ocean involved in the built up of the orogen was the Cambrian Iapetus Ocean and not the Adamastor proper.

6.7.1. Reworked basement

East of the small exposed segment of the Búzios Orogen, at the coastal region of the Rio de Janeiro State, the reworked Paleoproterozoic orthogneissic basement of the orogen crops out. The granitic orthogneiss was

ca. 2000 Ma, with metamorphic overprinting ages of ca. 520 Ma (Schmitt, 2000). It represents a supposed western continental margin of the Cambrian Búzios Orogen (Schmitt, 2000; Heilbron and Machado, 2003). This easternmost and youngest segment is also interpreted as an exotic fragment from the Congo Craton, amalgamated to the eastern MPV, during the waning stages of the Brasiliano collage (Fonseca et al., 1994, in: Schmitt, 2000).

6.8. Tocantins Province connections

The record of the Brasiliano III system of orogens within the Tocantins Province, is represented by the Paraguay Belt, probably related to the ca. 520 Ma Pampean Orogen in Argentina (Trompette, 1994) and coeval with the Búzios Orogen in MPV. In the south-eastern tip of the Tocantins Province, the interference of the Araçuaí Orogen (Brasiliano III) on the Socorro-Guaxupé Orogen (Brasiliano II) is well documented (Trouw et al., 2000; Campos Neto, 2000), particularly on the Andrelândia passive margin assemblage. This late collisional event is recognised by means of the north-west-directed ca. 560 Ma tectonic transport, overprinting an earlier east-directed ca. 630 Ma tectonic transport, giving rise to a highly complicated interference tectonic pattern (Trouw et al., 2000; Campos Neto, 2000).

The east-directed tectonic transport during the Brasiliano II orogen (Fig. 2) is attributed to the subduction of the São Francisco Plate underneath the Paraná Plate. The north-west-directed tectonic transport, in turn, was ascribed to the eastward subduction of these previously amalgamated São Francisco-Paraná plates under the Serra do Mar Microplate/Araçuaí Orogen arc (Trouw et al., 2000; Campos Neto, 2000). While the first orogenic episode is related to the consumption of the Goianides Ocean (the Brazilides Ocean from Unrug, 1997), the second is ascribed to the consumption of local branch of the Adamastor Ocean (Trouw et al., 2000; Campos Neto, 2000).

6.9. Pan-African connections

The Araçuaí and West Congo Neoproterozoic belts are counterparts of the Araçuaí-West-Congo Orogen: a confined orogen developed in an embayment outlined by the São Francisco and Congo cratons (e.g.

Brito-Neves and Cordani, 1991; Trompette, 1994; Pedrosa-Soares et al., 1998). The collisional stage in the West Congo Belt was dated at ca. 565 Ma (Tack and Fernandez-Alonso, 1998). The present integration provides a finer tuning for these correlations. The ca. 565 Ma D₁ syn-collisional peak age recorded from the south-western African side (Table 4) coincides, within error, with the ca. 580–560 Ma age range obtained for the collisional peak from the Araçuaí Orogeny (Silva et al., 2002a, 2003a).

The observation of east-vergent thrusting structures in the eastern metasedimentary (internal) domain suggests the possibility of the correlation of these deposits with the Congo Craton continental margin, during the AWCO-Araçuaí-West Congo pre-orogenic extensional phase (Pedrosa-Soares, personal communication).

Another important tool to this correlation attempt is furnished by the crystallisation ages of ca. 924–912 Ma (U–Pb SHRIMP), obtained on the pre-orogenic rift-related, bimodal volcano-plutonic association of the West Congo Belt (Tack et al., 2001). Additionally, the uppermost Mayumbiam rhyolitic lavas sequence yielded a zircon U–Pb SHRIMP age of 912 ± 7 Ma. The difference between the ages of the anorogenic Salto da Divisa granite (ca. 875 Ma) and the Mayumbiam lavas (ca. 912 Ma) suggest a migration of the thermal axis of the rift to the Brazilian side of the basin some 40 m.y. after the onset of the rifting process. Besides the age difference, the great thickness of the bimodal pile in the West Congo Orogen, compared to scarce occurrences of the rift-related magmatism in the Araçuaí Orogen suggests that the rift was asymmetric with a thermal axis located in the African side.

Outside the AWC, the system Brasiliano III has temporally equivalents in other short-lived, southern Pan-African orogens. These include: Kaoko, Coastal Branch of Damara, Gariep, Saldania, West African belts; the Pan-African terranes from Sri Lanka, Southern India, Madagascar, part of the Mozambique Belt, the Ross Orogeny (Antarctica) and the Delamarian Orogeny/Ellsworth-Whitmore Mountains Terrane in Australia (Table 4, and references therein). Within the Gariep and Damara orogen the breakup of the Rodinia Supercontinent took place from ca. 780 to 740 Ma (Frimmel and Frank, 1998), some 150 m.y. later than in the West Congo, characterising a sequentially opening from north to southwards.

Finally, the ca. 540–520 Pampean Orogen in Argentina and Paraguay (Rapela, 2000), was also developed synchronously with the waning stages of the Brasiliano III collage (Búzios Orogen). Nevertheless, this synchronism of the former (Pampean Orogeny), is related to the opening and consummation of the Cambrian Iapetus Ocean, instead of the Neoproterozoic Adamastor Ocean.

7. Conclusions

The picture which emerged from this integrated geochronological and field approach confirms and amplifies the conclusions of recent review works on the South America Neoproterozoic (Brito-Neves et al., 1999; Campos Neto, 2000; Trouw et al., 2000). The study also confirms the evolutionary path, through successive systems of orogens, marked by sequential and diachronous ocean opening and closure, subduction, crustal melting and metamorphic overprinting. It corresponds to successive and geographically diverse evolution of the Wilson's Cycle, from ca. 880 to 500 Ma, which gave rise to the final Western Gondwanaland Supercontinent amalgamation.

The Brasiliano Supercycle was characterised as a composite orogen (nomenclature after Wilson, 1968; Sengör, 1990), with distinct convergent plate boundaries, corresponding to the diachronic 'branched system of orogens' of (Brito-Neves et al., 1999; Campos Neto, 2000). Its protracted, successive convergent (orogenic) evolution from ca. 880 to 500 Ma comprises three major successive systems of orogens (Fig. 3a).

The onset of the Neoproterozoic orogenic magmatism is attributable to an early Cryogenian accretionary episode, which gave rise to an intraoceanic island arc, ascribed to the system of orogens Brasiliano I (subduction-controlled orogen). Later on, the tectonic evolution took place mainly as 'collision-controlled' orogen giving rise to the systems of orogens: Brasiliano II and III. The continuous convergence of the Paraná, São Francisco-Rio de La Plata and the African Kalahari-Congo plates, triggering continental-scale compressional transpressive tectonics, played a major role in this evolution. The integration of the U–Pb geochronological updated database on the MPV suggests modifications to the accepted internal boundaries between the distinct orogens forming the province. The

Araçuaí Orogen had its geographic limits expanded on the basis of the new U–Pb SHRIMP date obtained from its pre- to syn-collisional arcs (ca. 590–560 Ma), in order to encompass the former Rio Doce Orogen.

In addition to the new design of the provincial internal boundaries, the integrated analyses and re-interpretation of 180 zircon ages from 160 Neoproterozoic plutons provided a new consistent provincial granitic chronostratigraphy (Fig. 3; Table 3 and A). The integrated analyses of the chemical, structural, and geochronological data from the successive pre-, syn- and post-collisional magmatic pulses and metamorphic peaks, furnished a first general and precise picture of the orogenic evolution of the entire province. Accordingly, the study contributed to the general understanding of the timing and nature of this highly complex and extended Brasiliano/Pan-African Supercycle (Table 4).

The study reinforces from the geochronological point of view previous reconstruction models delineating an Araçuaí-Western Congo integrated evolution (AWCO) (Pedrosa-Soares et al., 1998) from breakup (ca. 900 Ma) to reamalgamation stages (ca. 560 Ma). It also reinforces the criticism from Silva et al. (1997, 2000a) and Frimmel and Frank (1998), on previous correlations between the ca. 560–550 Ma southern Pan-African and the ca. 640–600 Ma southern Brazilian orogens. Accordingly, an alternative temporal correlation of the ca. 550 Ma Saldania Orogeny with Ross Orogeny (in the Antarctic continent) and not with the southern Brazilian orogens was favoured.

The analysis of a large amount of U–Pb SHRIMP data allows a better definition of the extent of the Brasiliano overprinting over large basement paleotectonic polycyclic units, mainly on the controversial south-eastern limits of the São Francisco Craton. The U–Pb ages resetting and tectonic transposition (ubiquitously recorded into the Archean and Paleoproterozoic orthogneisses), indicates that the designation of São Francisco “Metacraton”, in the sense used by Abdelsalam et al. (2002) for the “Saharan Metacraton”, would be a best classification for this pre-Neoproterozoic unit.

A final assertion on the Neoproterozoic on both sides of the Atlantic is that the crucial distinction between the Neoproterozoic evolution in South America and Africa is based neither on the timing of the successive events, nor on the orogenic architecture, but on the scale of the earliest orogenic accretionary events. In South Amer-

ica, the known early juvenile crustal growth was very restricted, totalling perhaps less than 10% of the total exposed Brasiliano crust. On the other hand, the Pan-African orogens, especially from the north-west and east African continent, were much more efficient in terms of generation of new crust. The >650 Ma (post-Brasiliano I) evolution, shared with other Pan-African continental-collision orogens, show small-scale new crustal growth and widespread crustal recycling. It delineates a major role for continental lithospheric mantle delamination as has been demonstrated for the Pan-African Trans-Saharan Belt (Black and Liégeois, 1993). This is suggested in particular by: (i) extensive high-K calc alkaline and S-type magmatism; (ii) high-T/low-P metamorphism; (iii) major shear zones parallel to the cratonic limits; (iv) (scattered) thrust remnants of obducted ophiolites; (v) post-collisional alkaline magmatism; and (vi) marginal cratonic reactivation. These peculiarities favour the current interpretations in the Brazilian literature as evidence of a Himalayan-type evolution following a Cordilleran accretionary arc system.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at [doi:10.1016/j.precamres.2004.10.004](https://doi.org/10.1016/j.precamres.2004.10.004).

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