GENESIS OF NEOPROTEROZOIC GRANITOID MAGMATISM IN THE EASTERN ARAÇUAÍ FOLD BELT, EASTERN BRAZIL: FIELD, GEOCHEMICAL AND SR –ND ISOTOPIC EVIDENCE.

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ABSTRACT The Neoproterozoic granitoid magmatism of the Araçuaí Fold Belt (AFB) is an important element for the discussion of the evolution of this belt and its relationships with the African counterpart, the West Congo Belt. In the eastern part of the AFB, four different granitoid suites were recognized. The Nanuque Suite (NQS) comprises syn-tectonic peraluminous cordierite-bearing monzogranites. The São Paulinho Suite (SPS) consists of Th-rich peraluminous two mica or biotite- only granitoids. Calc-alkalic granitoids with magmatic epidote were grouped into the Itagimirim Suite (ITS) and post-tectonic charnockitic rocks were grouped into the Salomão Suite (SLS). Sm-Nd mineral isochron and Rb-Sr isochron yielded ages of respectively 761 Ma and 714 Ma for the Nanuque and São Paulinho suites. The general Sr-Nd isotopic characteristics of the granitoid suites and some country rocks indicate that the parental magmas were mostly the product of melting of the Paraíba do Sul metasediments. The chronological and genetic evolution of the Neoproterozoic plutonism can be envisaged in a model of east-dipping subduction zone, followed by a continental collision between the Brasiliano/Pan-African São Francisco (Brazil) and Congo (Africa) cratons and final episodes of uplift and collapse.

Keywords: granites, petrogenesis, geochemistry, isotopes, Neoproterozoic.

INTRODUCTION The Neoproterozoic granitoid magmatism in the Araçuaí Fold Belt is an important element for the discussion of the evolution of this belt and its relationships with the African counterpart, the West Congo Belt. These granitoids are also important economically, hosting tungsten mineralization and gemstone-bearing pegmatites. In the studied area, the granites are mainly explored as dimension stones, but pegmatites also occur, locally, containing gemstones of good quality (aquamarine, beryl and alexandrite).

In the northern part of the Araçuaí Belt, including the studied area, Pedrosa Soares *et al.* (1999) grouped the Neoproterozoic granitoids into five suites, named G1, G2, G3, G4 and G5. In this paper we present new field data for the granitoids in the eastern portion of the Araçuaí Belt (Fig. 1a), in the states of Bahia and Minas Gerais, and discuss their genesis based on geochemical and Sr-Nd isotopic data.

GEOLOGICAL SETTING The terranes hosting the granitoids investigated comprise the following sequences: Caraíba-Paramirim Complex, Paraíba do Sul Complex and Macaúbas Group (Fig. 1b).

The Caraíba-Paramirim Complex represents the Archean/ Paleoproterozoic basement, exposed in the northeastern portion of the area.

The Paraíba do Sul Complex, a gneissic-migmatitic unit, comprises metasedimentary rocks of upper amphibolite to granulite facies. Paleoproterozoic ages have been traditionally suggested for the deposition of these sediments, with an overprint of Transamazonian and Brasiliano tectono-metamorphic events. In the study area, this complex is represented by kinzigitic gneiss, intruded by the neoproterozoic granitoids. Sm-Nd isotopic data for the Paraíba do Sul paragneiss indicate T_{DM} model ages between 1.61 and 1.74 Ga, which are interpreted as an upper limit for the sources of the original sediments . Therefore, the deposition of these rocks most probably occurred during the Meso- or Neoproterozoic.

The Macaúbas Group represents a Neoproterozoic sedimentary sequence deposited on a continental passive margin.

In this paper, the Neoproterozoic granitoids (Fig. 1b) are grouped into four suites: i) Nanuque Suite (NQS), ii) São Paulinho Suite (SPS), iii) Itagimirim Suite (IGS) and iv) Salomão Suite (SLS).

PETROGRAPHY AND GEOCHEMISTRY OF THE GRANITOID SUITES **Cordierite-bearing granites - Nanuque Suite (NQS)** The NQS rocks include coarse- to very coarse-grained two-mica or muscovite-bearing porphyritic monzogranites. They often contain cordierite, sillimanite, monazite and garnet as varietal and/or accessory minerals. All the plutons show evidence of final crystallization at shallow levels, and micrographic, pseudogranophyric intergrowths. The mineralogical associations indicate that the magma must have begun to crystallize close to the stability of muscovite. The assumed crystallization trajectory indicates a pronounced decrease in pressure, passing near the subsolvus-hypersolvus limit (Celino 1999).

SiO_2 contents vary from 68% to 74% and TiO_2 from 0.1 to 1.1% (Fig. 2a). Na_2O values are in the range 2.00 - 2.37%, K_2O values are in the range 3.70% to 6,70%. Geochemical data reveal a strong peraluminous character (Fig. 2b), suggesting crustal derivation of the original magmas. During anatexis of metassedimentary rocks at medium to lower depths in the crust, garnet is an important phase in the melting-dehydration reaction of biotite. This would be indicated by the contents of trace elements normally enriched in garnet, such as heavy REE. Despite the variable La/Yb ratios (30-400) of these granites (Fig. 3), the dominant facies present high La/Yb ratios, suggesting that garnet could be an important stable phase in the residue of the original crust, indicating that melting occurred in deeper crustal levels.

Th-rich HHP granitoids - São Paulinho Suite (SPS) The SPS granitoids consist of medium-grained, often porphyritic, muscovite-biotite monzogranite to quartz monzonite, occurring in bodies concordant with country high grade metasediments of the Paraíba do Sul complex. They show a larger number of small ellipsoidal biotite clots (mm to cm sized), containing prismatic sillimanite crystals. The association with sillimanite indicates the restitic nature of these clots. Restitic biotite is almost free of inclusions, while magmatic biotite and muscovite have a large number of monazite, zircon and apatite inclusions. These accessory minerals also occur as individual grains in large amounts, clearly exceeding their normal abundance in granitoid rocks.

The SPS granitoids are peraluminous (Fig. 2b) and rich in TiO_2 (Fig. 2a), P_2O_5, La, Ce (Fig. 3) Zr and Th, which correlates well with the modal contents of apatite, zircon and monazite. The combination of a relatively high U (10 ppm) and K_2O (6,30 %) contents with a very high content of Th (250 ppm), gives an estimated average heat production of 20,8 mWm^{-3} for these granites. This is 9 to 10 times higher than the usual values for granitoid rocks (Ashwal *et al.* 1992), allowing to consider them as High Heat Production (HHP) granitoids.

High Al-hornblende magmatic epidote-bearing granitoids - Itagimirim Suite (IGS) Magmatic epidote (mEp), in variable amounts and in several textural relationships, is found in calc-alkalic granitoids in the Eastern Araçuaí Belt. They intrude intermediate-grade metasediments of the Paraíba do Sul Complex or higher-grade metamorphic rocks of the Caraíba- Paramirim Complex (Fig. 1b). Most mEp-bearing plutons have been emplaced as elongate stocks or, less often, as dikes. The rapid ascent of granitic melt prevented epidote dissolution by the host magma.

In the Caraíba-Paramirim Complex, the Itagimirim stock and several bodies show SiO_2 around 67%, TiO_2 = 0.2 - 1.4%, (Fig. 2a), K_2O = 4 - 5% and MgO around 1%. These rocks are slightly more Sr-enriched (200-1000 ppm) than mEp-bearing granitoids in the Cachoeirinha-Salgueiro Terranes - CST - (Sial *et al.* 1997), but Ba is within a similar range (500-2000ppm). The Zr content is relatively high (~200 ppm) while Nb (~20 ppm) is low. In these plutons, both mafic enclaves and granodiorite hosts are metaluminous (Fig. 2b).

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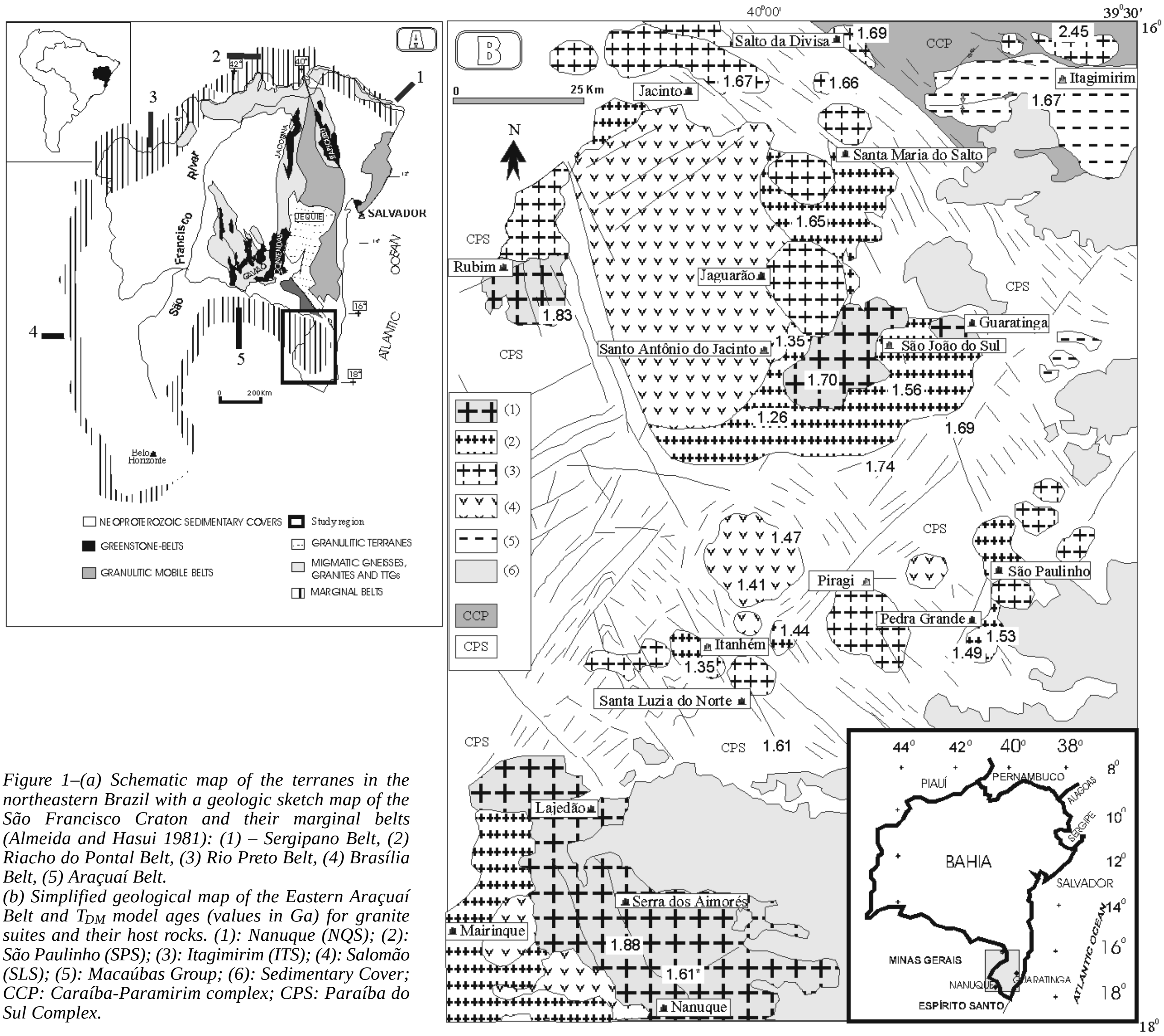

Figure 1–(a) Schematic map of the terranes in the northeastern Brazil with a geologic sketch map of the São Francisco Craton and their marginal belts (Almeida and Hasui 1981): (1) – Sergipano Belt, (2) Riacho do Pontal Belt, (3) Rio Preto Belt, (4) Brasília Belt, (5) Araçuaí Belt.
(b) Simplified geological map of the Eastern Araçuaí Belt and T_{DM} model ages (values in Ga) for granite suites and their host rocks. (1): Nanuque (NQS); (2): São Paulinho (SPS); (3): Itagimirim (ITS); (4): Salomão (SLS); (5): Macaúbas Group; (6): Sedimentary Cover; CCP: Caraíba-Paramirim complex; CPS: Paraíba do Sul Complex.

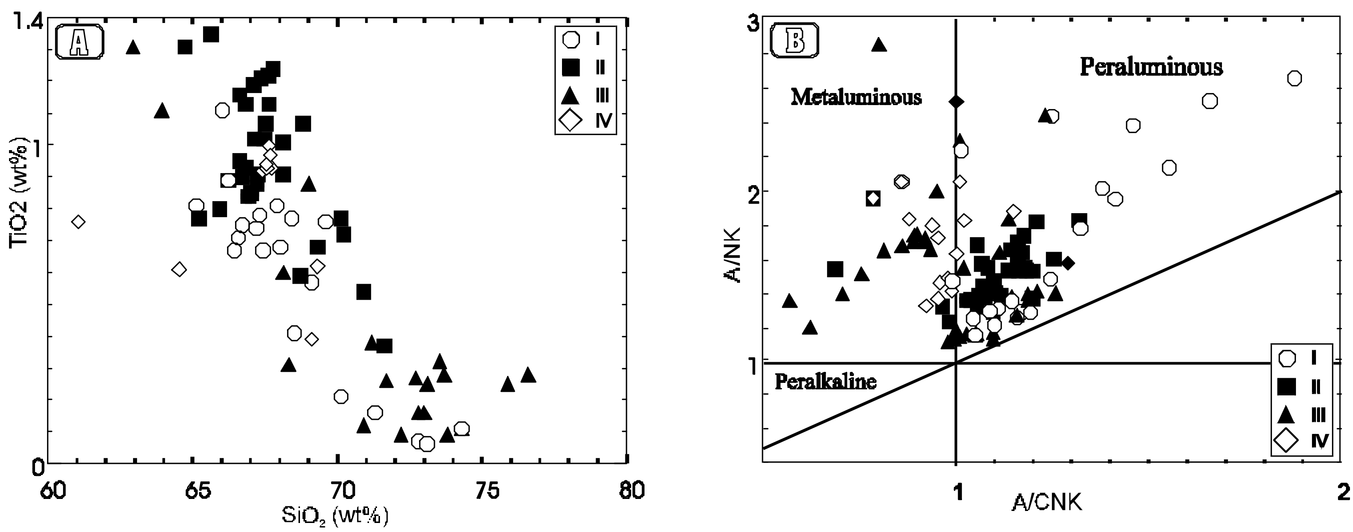

Figure 2–(a) SiO2 versus TiO2 diagram. (b) A/CNK versus A/NK diagram, using Shand's index (Maniar and Piccolli 1989). (I) Nanuque Suite (NQS), (II) São Paulinho Suite (SPS), (III) Itagimirim Suite (IGS) and (IV) Salomão Suite (SLS).

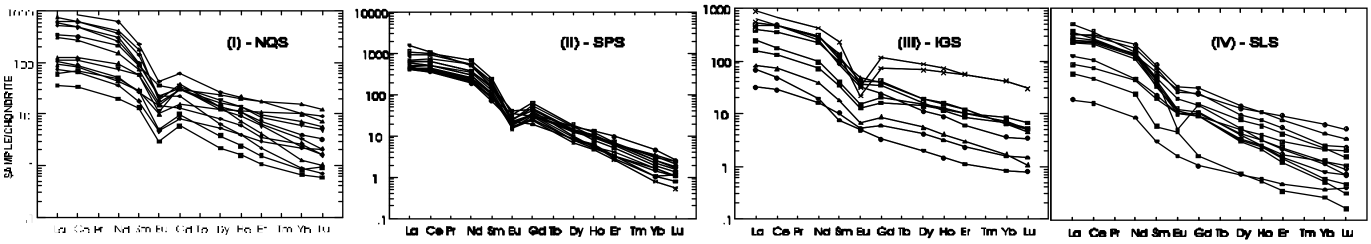

Figure 3 – Normalized REE diagrams; normalizing values from Sun (1982).

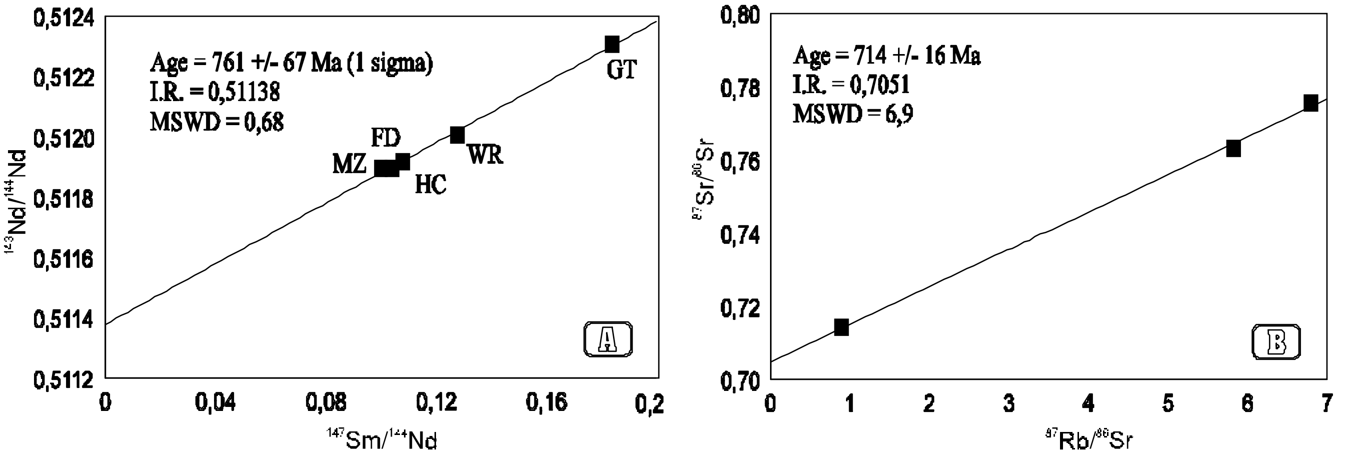

Figure 4–(a) Mineral isochron of the Nanuque Suite (NQS). GT=garnet; FD=Feldspar; MZ=monazite; HC=heavy minerals concentrated; WR=whole rock. (b) Rb-Sr reference isochron (whole-rock) of the São Paulinho Suite (SPS).

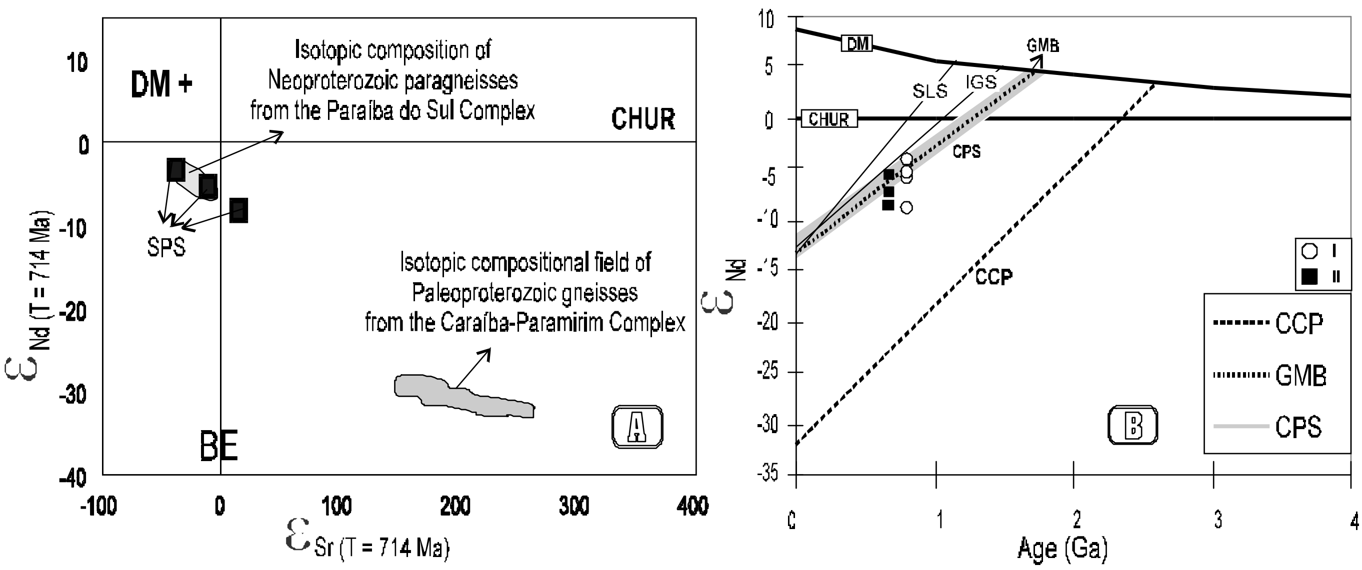

Figure 5–(a) Isotopic Sr and Nd compositions of SPS granites, calculated for 714 Ma. Isotopic composition of the paleoproterozoic gneisses from Sato (1998). (b) ε_{nd} versus age (Ga) diagram showing the initial Nd isotopic composition of 761 Ma (NQS) and 714 Ma (SPS) granitic suites, and the isotopic composition of : (I) Nanuque Suite (NQS), (II) São Paulinho Suite (SPS), Itagimirim Suite (IGS), Salomão Suite (SLS) and Caraíba-Paramirim Complex (CCP), Paraíba do Sul Complex (CPS) and Macaúbas Group (GMB) (Celino 1999).

Chondrite-normalized REE patterns show enrichment in LREE, depletion in HREE and a weak Eu anomaly (Fig. 3) and are similar to the patterns of the granodiorites of the CST. In a FeO*/MgO versus (Zr+Nb+Ce+Y) diagram, early IGS granitoids plot in the I-type field while late facies plot in the A-type field (Fig. 7a).

Orthopyroxene-bearing granitoids - Salomão Suite (SLS)

The SLS comprises a group of charnockitic rocks with relict magmatic textures. SiO_2 values range from 52% to 71%. The rocks are enriched in Ti (Fig. 2a), P, Zr, Ba and REE. The SLS granitoids show a metaluminous (Fig. 2b), with conspicuous enrichment in LIL and HFS elements, plotting mainly in the field of A-type granitoids in a FeO*/MgO versus (Zr+Nb+Ce+Y) diagram (Fig. 7b). These features indicate some degree of mantle contribution to the parental melt. Fractional crystallization was probably the main differentiation process during the evolution of the charnockitic suite (Celino 1999).

Thermobarometric calculations suggest temperatures between 600 and 700^{0}C and pressure of 4,5 kbar (~20 km depth) for the crystallization of these rocks (Celino 1999). Field evidence, supplemented by mineralogical, textural and chemical data, suggests an origin by partial melting of deep continental crust under dry conditions of granulite facies (Celino 1999).

Sr AND Nd ISOTOPES The Sm-Nd mineral isochron for Nanuque Granitic Suite (NQS) yielded an age of 761±67 Ma (Fig. 5a), which show ε_{Nd}(t) between - 4.9 and - 8.4 and T_{DM} model ages between 1.69 Ga and 1.88 Ga (Fig. 1, Table 1). The Rb-Sr isochron for São Paulinho Suite (SPS) yielded na age of 714 ± 16 Ma and a initial $^{87}Sr/^{86}Sr$ ratio of ca. 0.7051 (Fig. 4b). The initial ratio, demonstrates the contribution of older sialic material in the original granitic magma (Fig. 5a). This is confirmed by the Sm-Nd isotopic data, which show ε_{Nd}(t) between – 3.2 and – 9.3 (Fig. 5b) and T_{DM} model ages between 1.26 Ga and 1.65 Ga (Fig. 1). The Nd isotopic composition (Table 1) for Itagimirim Suite (IGS) indicates $\varepsilon_{Nd(t)}$ between – 5.5 and – 6.9 (Fig. 5b) and T_{DM} model ages between 1.49 Ga and 1.69 Ga (Fig. 1). The ε_{Nd}(t) values for Salomão Suite (SLS) are – 4.5 to – 5.5 (Fig. 5b) and T_{DM} model ages between 1.41 Ga and 1.47 Ga (Fig. 1).

Sr and Nd isotopic composition of the SPS, and the general Nd isotopic characteristics of the rest of the granitoid suites indicate that the parental magmas are mostly the product of remelting of the Paraíba do Sul metasediments (Fig. 5a).

These isochron ages are somewhat older than the peak of granitic magmatism observed for most intrusions in Brasiliano/Pan-African belts in Brazil. Due to the strong crustal imprint into the original melts, one should be cautious before interpreting them as true crystallization ages, since some inheritance effect could potentially be present.

CONCLUSIONS These granites represent mostly anatectic melts from deep crust and reflect its composition (Fig. 5b). Within the investigated area, the combined field, geochemical and isotopic data provide a framework for tracing the chronological and genetic evolution of the Neoproterozoic plutonism . This can be envisaged in relation to the orogenic stages of subduction, continental collision (Fig. 6), transpression, uplift and collapse (Fig. 7).

A polycyclic evolution is suggested for the Paraíba do Sul Complex begins with an east-dipping subduction beneath the Brasiliano São Francisco Craton followed by a continental collision with the Pan-African Congo Craton. Coinciding with a NW large-scale transport caused by the backthrust of the upper plate and final overthrust of the lower plate, the marginal areas of the São Francisco Craton, were thermo-tectonically overprinted and transformed into the so-called Paraíba do Sul Complex (Fig. 6a).

The deposition of supracrustal rocks related to the Brasiliano Cycle, typified by Macaúbas Group took place during Meso- to Neoproterozoic times (Fig. 6a). The emplacement of syn- to late-tectonic intrusions occurred in synchrony with the transition from a SE/NW-directed compressive regime (D_{p-1} structures) to a NE/SW-directed compressive regime (D_p structures) (Celino 1999). During this period, large volumes of S-type granitoids (NQS and SPS) were

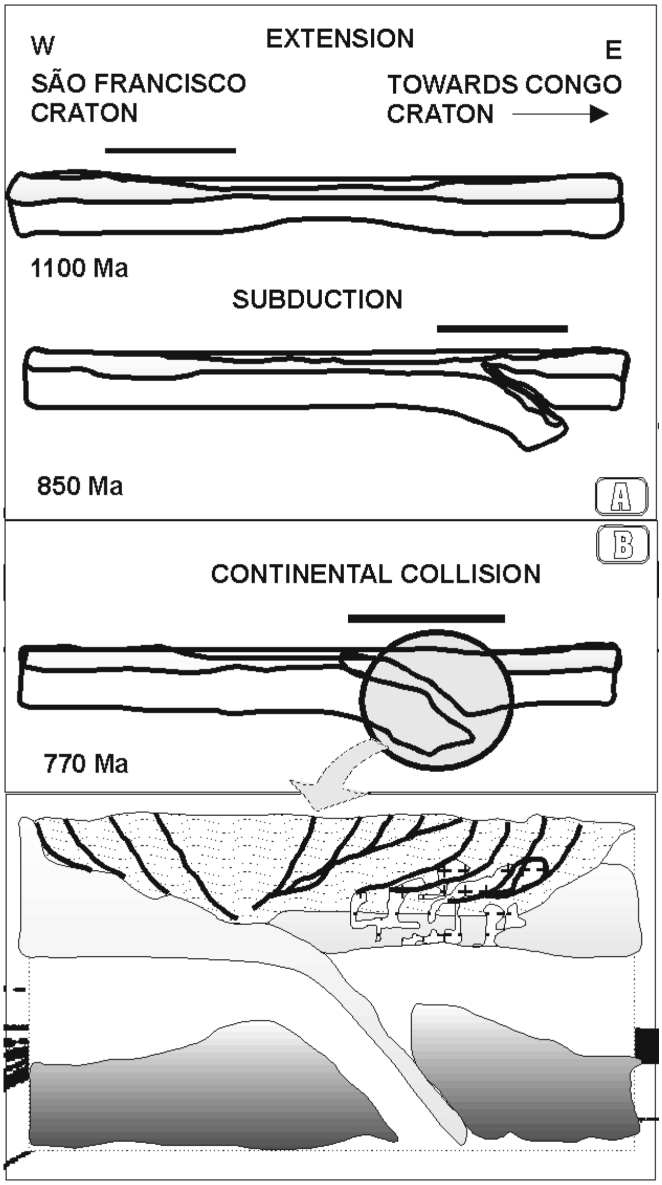

Figure 6–Model for the geodynamic evolution of the Eastern Araçuaí Belt. (a): Polycyclic evolution suggested for the Paraíba do Sul Complex. (b) Tectonic model for genesis and emplacement of NQS and SPS suites.

formed, whereas the formation of calc-alkalic bodies was the local exception (Fig. 6b).

The emplacement of post-tectonic intrusions (IGS and SLS) followed and was related to NS reactivated zones. The IGS granitoids, that presumably fractionated from crustal magmas, are indicative of early and/or rapid uplift and crustal thinning in the orogenic hinterland (Celino 1999), with concomitant upper mantle anatexis by pressure release melting (Fig. 7a). A final episode of magmatism was activated in consequence of the proceeding post-collisional uplift. This episode is characterized by numerous bodies of A-type granitoids and the charnockites of the Salomão Suite (SLS) (Fig. 7b).

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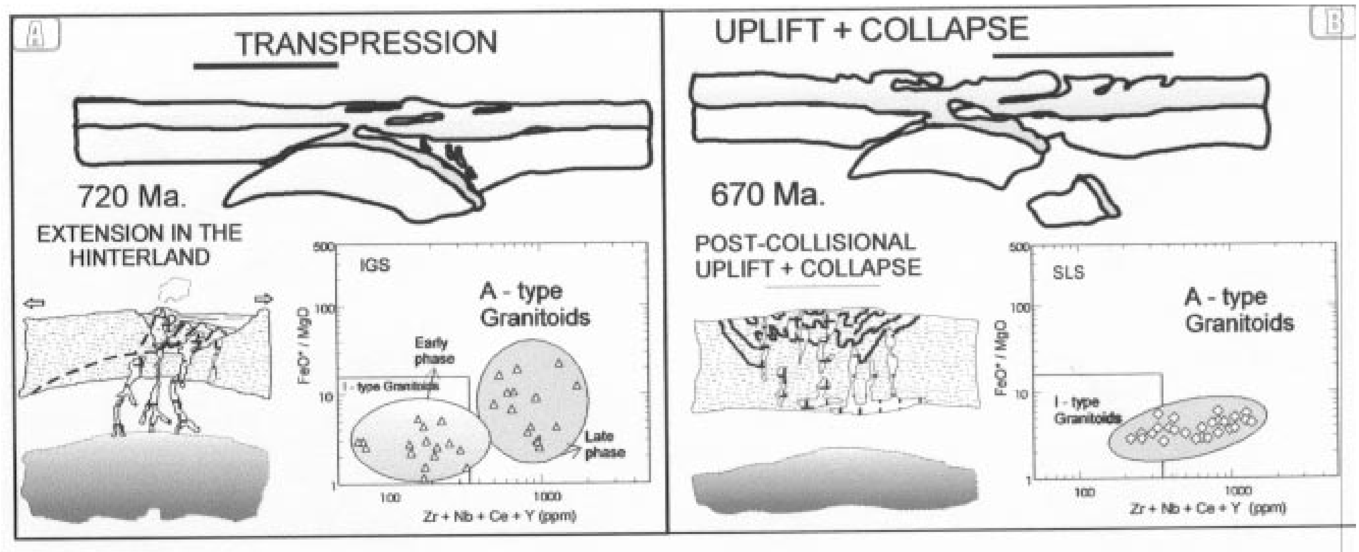

Figure 7–Model for genesis and emplacement of the post-tectonic intrusions and plotting of the granitoids in the discriminant diagram of Whalen et al. (1987). (a): Itagimirim Suite (ITS); (b): Salomão Suite (SLS).

Table 1–Geochemical, geochronological data and Nd isotopic characteristics of granites and their host rocks in southernmost Bahia. ε_{nd} for Itagimirim and Salomão suites are calculated for 700 Ma; ε for the host rocks are calculated for 750 Ma.
GMP: Macaúbas Group; CCP: Caraíba-Paramirim Complex; CPS: Paraíba do Sul Complex.

Rock unit	Sm (ppm)	Nd (ppm)	Sm/Nd	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd$	initial ε_{Nd}	T_{DM} (Ga)
Host rocks							
CCP	4,049	28,320	0,1430	0,0864	0,51059	-22,09	2,447
CPS	5,550	29,092	0,1908	0,1153	0,51137	-6,73	1,736
CPS	8,262	42,663	0,1937	0,1171	0,51141	-5,92	1,690
GMB	93,574	491,100	0,1905	0,1152	0,51141	-5,94	1,673
CPS	7,587	39,425	0,1924	0,1163	0,51146	-5,04	1,612
CPS*	7,229	37,533	0,1926	0,1163	0,51146	-5,04	1,612
Nanuque Suite (NQS)							
Nanuque	8,037	35,880	0,2240	0,1354	0,51139	-5,15	1,879
Rubim	3,550	16,710	0,2124	0,1280	0,51137	-5,64	1,827
Jaguarão	19,730	127,300	0,1550	0,0940	0,51123	-8,31	1,697
Lajedão	2,271	8,111	0,2800	0,1693	0,51140	-4,94	-
São Paulinho Suite (SPS)							
Jaguarão	2,624	15,500	0,1693	0,1023	0,51135	-7,16	1,647
Sto. Antônio	10,200	86,630	0,1177	0,0712	0,51151	-9,28	1,559
Sta. Luzia	30,130	234,300	0,1286	0,0777	0,51139	-6,42	1,437
Sto. Antônio	44,670	322,300	0,1386	0,0838	0,51149	-4,42	1,352
Sta. Luzia	36,290	277,000	0,1310	0,0792	0,51148	-4,74	1,348
Sto. Antônio	57,380	437,300	0,1312	0,0790	0,51155	-3,22	1,261
Itagimirim Suite (IGS)							
Salto Divisa	41,117	215,500	0,1908	0,1153	0,51141	-6,31	1,691
Salto Divisa	46,310	235,030	0,1970	0,1190	0,51145	-5,57	1,669
Salto Divisa	47,650	250,300	0,1904	0,1151	0,51143	-5,96	1,662
Pedra Grande	17,210	115,300	0,1493	0,0902	0,51138	-6,87	1,526
Pedra Grande	20,170	136,450	0,1478	0,0890	0,51140	-6,49	1,494
Salomão Suite (SLS)							
Salomão	15,020	94,950	0,1582	0,0956	0,51146	-5,48	1,472
Salomão	19,240	123,050	0,1564	0,0950	0,51150	-4,59	1,410

* xenolith in NQS

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