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NEOPROTEROZOIC WESTERN GONDWANA ASSEMBLY AND SUBDUCTION-RELATED PLUTONISM: THE ROLE OF THE RIO NEGRO COMPLEX IN THE RIBEIRA BELT

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ABSTRACT The assembly of Western Gondwana, during the Neoproterozoic, involved the São Francisco/West Congo Craton and its passive margins. The Ribeira Belt lies along the Brazilian Atlantic Coast and is one of the products of the supercontinent amalgamation. Collisional processes were preceded by subduction, recorded by the Rio Negro Complex orthogneisses at the Ribeira Belt. Its plutonites represent a gabbro-diorite-tonalite-throndhjemite plutonic series that evolved from 637 Ma (U-Pb zircon age of the tonalite gneiss) to nearly 600 Ma, at the beginning of the collisional event. Field, petrographic, litogeochemical, and isotopic characteristics of the Rio Negro Complex point to magmatism at a very mature oceanic arc or an immature continental crust as seen along attenuated passive margins. In the latter hypothesis, the margin could be related to a microplate or to the Congo/Angola Craton.

INTRODUCTION The São Francisco/West Congo Craton is surrounded by Brasiliano/Pan-African belts (720-550 Ma) that evolved during the agglutination of the Gondwana Supercontinent. The Ribeira Belt (Almeida *et al.* 1973), one of these belts, lies along the Brazilian Atlantic Coast (Fig. 1). This work deals with new geochemical and isotopic data on pre-collisional orthogneisses of the Rio Negro Complex belonging to the belt and the role of the magmatism in the tectonic evolution.

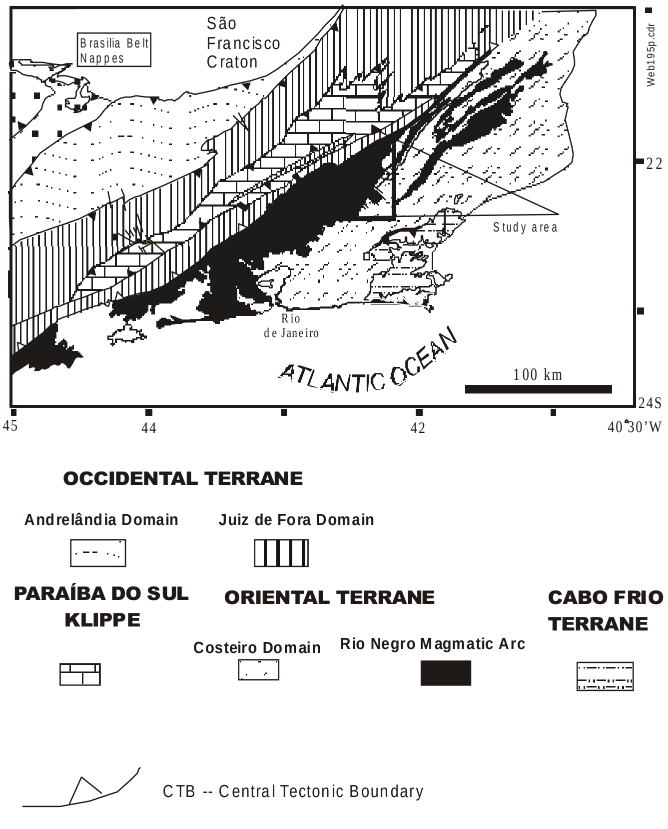

Figure 1-Tectonic map of the Central Ribeira Belt. Modified from Heilbron et al., 2000

TECTONIC SETTING The major tectonic framework of the Ribeira Belt (Fig. 1) is defined by two distinct terranes (Heilbron *et al.*. 2000). The Occidental Terrane comprises a pile of superposed allochtonous terranes thrusted to the west (Heilbron *et al.* 1995) and subsequently deformed in transpressional regime, with large vertical oblique shear zones associated with granitic plutons (Ebert *et al.* 1991). It is considered as the early São Francisco Craton passive margin (Heilbron *et al.* 2000). The Oriental Terrane (or Costeiro Domain, Machado *et al.* 1996; Serra do Mar Microplate, Campos Neto and Figueiredo 1995) is characterized by large isoclinal recumbent folds, low angle dipping metamorphic foliation, and numerous NW trending ductile-ruptile shear zones containing post-collisional granitoids (Tupinambá 1999).

In the central segment of the Ribeira Belt (Fig. 1), the western edge of the Oriental Terrane is marked by a moderate northwest dipping (~35^o) shear zone — the Central Tectonic Boundary (Almeida *et al.* 1998). The Oriental Terrane was divided by Heilbron *et al.* (2000) into three tectono-magmatic domains: the Rio Negro Magmatic Arc and the Costeiro and Cabo Frio domains (Fig. 1).

The RNC (Rio Negro Complex, Tupinambá *et al.* 1996) comprises tonalitic to trondhjemitic orthogneisses, hornblende gabbro and quartz diorite stocks from subduction-related magmatism. Sin-collisional leucogranites with banded and homophonous textures crosscut the Rio Negro Complex orthogneisses (Tupinambá 1999). A megasheet of granodioritic to granitic orthogneiss (Serra dos Órgãos Batholith, Barbosa and Grossi Sad 1985) was emplaced during the sin- to late-collisional orogenic phase. Late to post-collisional non-foliated granite stocks and sills are also present (Junho 1990). The country rocks of the plutonites are high-grade metasediments of the Paraíba do Sul Group (Ebert 1968), comprising garnet-(cordierite)-(sillimanite)-biotite gneisses, quartzites, calc-silicate rocks and marbles. The studied area is located along the northern edge of the Rio Negro Magmatic Arc, which occupies 2/3 of the area of the Oriental Terrane, almost 600-km along the Atlantic Coast, from northern São Paulo to southern Espirito Santo (Fig.1).

The main deformation in the Oriental Terrane is characterized by: a) migmatitic and locally mylonitic foliation within the metasedimentary rocks; b) folding of this foliation by kilometer-scale recumbent folds with NW dipping axial plane and N trending axis; b) coarse grained foliation and discrete shear zones within the orthogneisses, parallel to the recumbent folds axial plane. Late deformation is represented by two sets of normal open to tight folds with NE and NW trending axis. Discrete vertical dipping transpressional and transtensional shear zones are also related to the late stage deformation.

The RNC orthogneisses were formerly considered as a Paleoproterozoic basement (Machado and Demange 1994). Published Rb-Sr isochronic ages of granitoid gneisses from the Oriental Terrane similar to the RNC rocks are usually older than 600 Ma (Fonseca *et al.* 1984, Batista and Kawashita 1985, Tassinari 1988, Dias Neto *et al.* 1995, Machado 1997). A leucogranite gneiss closely related to the Rio Negro Complex yielded a 620 +/- 20 Ma concordant zircon age (Delhal *et al.* 1969, Tupinambá *et al.* 1997). In the northern Ribeira Belt, orthogneisses from the Rio Doce Magmatic arc (Figueiredo and Campos Neto 1993) yielded younger U-Pb zircon ages (590 to 570 Ma, Söllner at al 1991).

TONALITIC GNEISSES OF THE RIO NEGRO COMPLEX The rocks of the Rio Negro complex were first described as stromatic or nebulitic migmatites and included in the *Serra dos Órgãos Series* (Rosier 1957), *Santo Aleixo, Bingen* (Penha *et al.*. 1979) *and Rio Negro* (Matos *et al.* 1980) units. However, the absence of melanosome or

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leucosome enrichments, the presence of igneous-looking textures and magmatic crosscutting led Tupinambá *et al.* (1996) to consider these rocks as a metaigneous complex.

The most widespread and representative rock of the complex is a coarse-grained hornblende bearing tonalite gneiss. Its gneissic fabric is due to planar aggregates of hornblende and biotite. These minerals, along with quartz and plagioclase (oligoclase), are the main constituents of the gneisses, whereas titanite and zircon are accessory mineral phases. Isolated poiquiloblastic crystals of hornblende and biotite, lobate contacts and anhedral quartz are interpreted as igneous minerals and textures. Subsequent dynamic metamorphic reactions produced aggregates of titanite, opaque minerals and tiny biotite flakes. Granoblastic textures including plagioclase, quartz and even hornblende may be also present. Layered sills and stocks of hornblende gabbro and gabbronorite, with hornblendite cumulates at the base and trondhjemite composition at the top, also occur within the Rio Negro Complex. Diorite and quartz diorite gneiss is associated with tonalite gneiss both in outcrop and map scales (Fig. 2).

RESULTS AND DISCUSSION

Litogeochemistry Twenty-three samples of gabbros, diorite, and tonalite from the RNC were collected near the cities of Nova Friburgo and Duas Barras (not shown in Fig. 1) and were analyzed at ACTLABS, Ontario, Canada. Table 1 contains major and selected trace element concentrations of tonalite gneiss samples.

The plutonic series is mainly tonalitic in composition but some sodic members are trondhjemitic in composition (Fig. 3a). The hornblende bearing metaluminous character is also clear (Fig. 3b). Na_2O and TiO_2 contents show positive correlation on Harker-type diagrams (some trends in Figure 3c); FeO (total), MgO, CaO e MnO show negative correlation. K_2O is almost constant between 1,5 and 2,0 %, contrasting with high CaO concentration, that reaches almost 10 %. Similar chemical parameters were compiled by Barbarin (1999) to delineate typical subduction-related low K-high Ca calc-alkaline series (H_{CA} type). In a diagram using incompatible elements (Pearce *et al.* 1983), the samples plot in the volcanic arc field (Fig. 3d). In the R1x R2 diagram (Batchelor and Bowden, 1985) the RNC samples plot mainly within the pre-collisional field (Fig. 3e).

U/Pb zircon age

We have obtained a U-Pb zircon age from a 30 kg tonalite gneiss sampled in a quarry (20º 30'42" S; 42º 31'33"W) located two kilometers NE of Duas Barras (not shown in Figure 1). Its typical zircon grains (5:1) are well crystallized and rich in rutile inclusions. Analyses of four zircon fractions with different magnetic properties were performed at CPGeo/USP (Table 2), which plotted in a concordia diagram (Fig. 4) yields an upper intercept age of 634 ± 10 Ma. This age is interpreted as the magmatic age of the tonalite.

Figure 2-Field relations between tonalite gneiss (white) and diorite gneiss (black) of the Rio Negro Complex. The fields sketches show tonalite pods interlayered with diorite gneiss, oppositely, small irregular blocks and pods of diorite gneiss also occur within larger tonalite gneiss stocks.

Table 1-Chemical analytical data from tonalite gneiss of the Rio Negro Complex from Nova Friburgo, Duas Barras and Sumidouro.

	DB-I-53	DB-TUP-8o,r	DB-TUP-8m	CO-TUP-2E	DB-TUP-30D	DB-III-54	DB-I-8
SiO_2	54.42	54.76	66.23	61.93	62.10	68.98	75.76
TiO_2	1.04	0.97	0.62	0.63	0.60	0.45	0.02
Al_2O_3	17.10	18.11	17.72	15.95	17.02	14.81	15.24
FeO*	8.69	6.54	2.80	5.29	5.34	3.04	0.45
MnO	0.17	0.13	0.04	0.13	0.12	0.09	0.01
MgO	3.84	3.44	1.65	2.34	2.53	0.86	0.06
CaO	6.83	7.13	4.87	5.47	6.21	3.00	3.76
Na_2O	2.86	3.97	4.43	3.90	4.12	6.51	4.76
K_2O	2.15	1.86	1.39	1.69	1.72	2.11	0.24
P_2O_5	0.30	0.32	0.22	0.17	0.17	0.15	-0.01
LOI	0.74	0.91	0.67	0.44	0.47	0.23	0.42
TOT	98.14	98.14	100.64	97.94	100.4	100.23	100.71
Rb	56	38	44	75	57	64	3
Nb	8.5	5.1	17.0	18.7	7.0	6.0	2.0
Y	23	36	6	68	24	26	3

Analyses at ACTLABS, Ontario, Canadá. Concentration of major elements in %. Minor and trace elements in ppm.

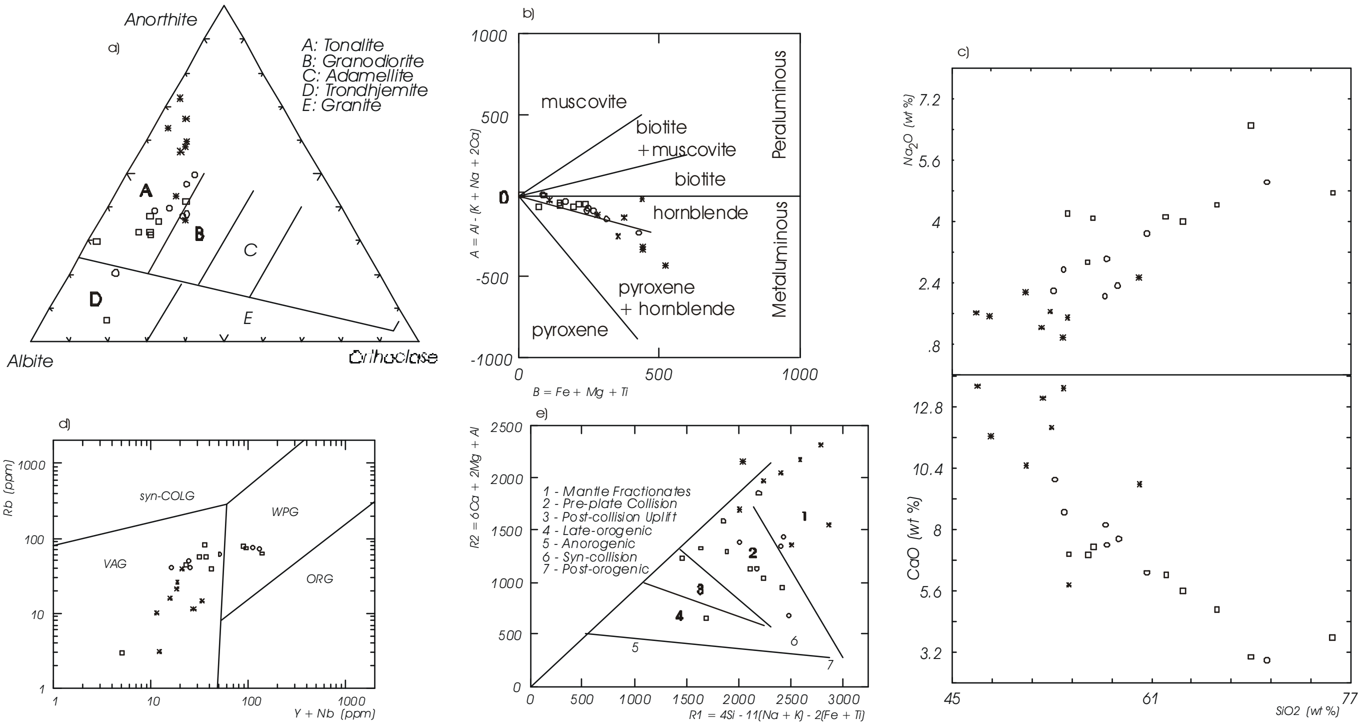

Figure 3-Litogeochemistry of the samples from the Rio Negro Complex. Asterisks: gabbro; circles: diorite to quartz diorite gneiss; squares: tonalite gneiss. A) tonalite to trondhjemite composition on a normative albite-anorthite-orthoclase triangular diagram; b) hornblende-bearing metaluminous character of the series (De Bon and Le Fort, 1980); c) Harker-type variation diagram for Na_2O and CaO; d) volcanic arc component of the samples in the trace-element diagram of Pearce et. al (1984); e) pre-collisional trend of non-cumulate rocks in the R1xR2 diagram of Batchelor and Bowden (1982)

Table 2-U-Pb analytical results from a tonalite gneiss (sample DB-TUP-30D).

fraction (1)	sample weight	concentration (2)		observed (3)	isotopic ratios (4)			ages (5)		
	(g)	U (ppm)	Pb (ppm)	^{206}Pb / ^{204}Pb	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$
m (- 1)	0.00047	171.44	17.83	1092.3	0.096394	0.80718	0.060732	593	601	630
m (- 2)	0.00210	35.64	3.87	1068.9	0.099918	0.83785	0.060816	614	618	633
m (- 3)	0.00054	292.88	27.82	1912.4	0.089705	0.75067	0.060693	554	569	629
m (- 4)	0.00279	58.02	6.10	1863.6	0.098745	0.83159	0.061080	607	615	642

General analytical procedures of the CPGeo/USP in Basei *et al.* (1991). 1: m - magnetic fractions. numbers in parentheses indicated the tilt used on Frantz separator at 1.5 amp. current; all fractions contain prismatic. huge (5:1) and yellowish zircons with rutile inclusions. 2: Total U and Pb concentrations corrected for analytical blank; 3: Not corrected for blank or non-radiogenic Pb; 4: Radiogenic Pb corrected for blank and initial Pb; U corrected for blank; 5: Ages given in Ma using Ludwig's ISOPLOT program (1993).

Nd and Sr isotopic data Three Nd isotopic analyses were performed (Table 3). The more basic rocks yielded lower $e_{Nd\ 630\ Ma}$ values: – 4 for hornblende gabbro and – 5 for diorite gneiss; the tonalite gneiss sample yields the highest $\varepsilon_{Nd\ 630\ Ma}$ value ever reported in Neoproterozoic igneous rocks at the Ribeira Belt: — 1. This difference is also reflected in the T_{Dm} Model Ages, which are 1.8 Ga for hornblende gabbro and diorite gneiss and 1.3 Ga for the tonalite gneiss.

Sr isotopic ratios from the RNC (Table 4) range from 0.7045 (tonalite gneiss) to 0.7085 (diorite gneiss); the more basic is the rock the higher is its $(^{87}Sr/^{86}Sr)_{630\ Ma}$ ratio. The $^{87}Sr/^{86}Sr$ heterogeneity is probably due to subsequent metamorphic and hydrothermal processes. The differential isotopic enrichment is reflected in the extremely high MSWD value (~ 690) of the seven points reference isochron, which yields an age of 656 ± 5 Ma and $^{87}Sr/^{86}Sr$ initial ratio of 0.7076. The relatively high $^{87}Sr/^{86}Sr$ initial ratio is probably related to country-rock assimilation during transport and emplacement.

Tectonic implications The geochronological and geochemical data presented and the analyses of previously published data suggest that a Neoproterozoic magmatic arc was active at the Oriental Terrane of the Ribeira Belt during the pre-collisional phase of the Brasiliano-Pan African Orogeny. The collisional stage, which marks the end of subduction-related magmatism, is represented by an extensive crustal melting that led to leucogranite generation at 600 Ma (Tupinambá 1999). Therefore, the evolutionary period of the arc (640 to 600 Ma) is not related to the Rio Doce Magmatic Arc (590-560 Ma, Campos Neto and Figueiredo 1995) but fits the same interval proposed for the pre-collisional phase of Brasiliano Orogeny in other mobile belts around São Francisco Craton (Brito Neves and Cordani 1991).

It is noteworthy that pre-collisional magmatic rocks are not known in the Occidental Terrane of the Ribeira Belt. It carries, instead, many

Table 3–Sm-Nd whole rock analytical data.

sample	rock	Sm (ppm)	Nd (ppm)	$^{147}Sm/^{144}Nd$	error	$^{143}Nd/^{144}Nd$	error	T_{DM} DePaolo	$\varepsilon_{(0)}$	$\varepsilon_{(630)}$
CO-TUP-7B	diorite gn	7.791	33.347	0.1413	0.0005	0.512178	0.000044	1.8	-9	-5
DB-TUP-30D	tonalite gn	4.224	19.335	0.1321	0.0004	0.512337	0.000037	1.3	-6	- 1
DB-FR-34A	hbl gabbro	6.430	26.955	0.1443	0.0005	0.512229	0.000040	1.8	-8	- 4

Analyses at CPGeo-USP, using isotope dilution. gn: gneiss; hbl: hornblende

Table 4–Rb-Sr whole rock analytical data.

Sample	Rock	Rb (ppm)	Sr (ppm)	$^{87}Rb/^{86}Sr$	error	$^{87}Sr/^{86}Sr$	error	$(^{87}Sr/^{86}Sr)_{630}$
DB-TUP-8I	qtz diorite gn	65.10	467.90	0.4030	0.0110	0.71047	0.00015	0.70685
DB-TUP-8F	qtz diorite gn	56.90	535.50	0.3080	0.0090	0.70952	0.00014	0.70675
DB-TUP-8o.r	tonalite gn	43.43	736.08	0.1708	0.0023	0.70880	0.00008	0.70727
CO-TUP-2F	tonalite gn	57.00	274.00	0.6020	0.0170	0.71346	0.00008	0.70805
DB-FR-34A	hbl gabbro	11.20	423.62	0.0765	0.0007	0.70848	0.00001	0.70779
DB-TUP-30D	tonalite gn	48.61	347.86	0.4045	0.0040	0.70927	0.00001	0.70564
CO-TUP-7B	diorite gn	54.53	244.15	0.6468	0.0055	0.71438	0.00001	0.70857

Analyses at CPGeo-USP, using isotope dilution. gn: gneiss; hbl: hornblende

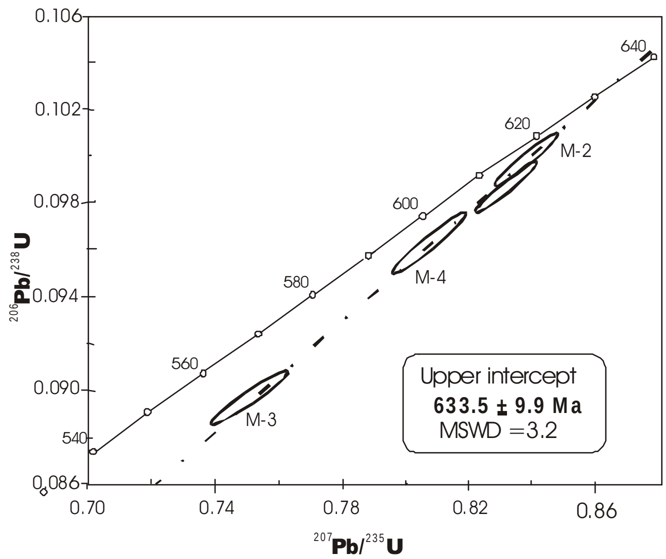

Figure 4-Concordia diagram, sample DB-Tup-30d. Analytical data in Table 2

sin- to late collisional granitoids. The existence of a magmatic arc at the Oriental Terrane brings new constraints on the palaeogeography of the Brasiliano/Panafrican orogeny. It implies that: a) during the Neoproterozoic assembly of Western Gondwana the closure of an oceanic basin produced the Rio Negro Magmatic Arc; b) the dip of the early subduction zone was to the East, in order to produce a magmatic arc only at the Oriental Terrane; c) the main phase of deformation and metamorphism in the central segment of the Ribeira Belt was caused by the collision of the São Francisco Craton passive margin (Occidental Terrane) with the Rio Negro Magmatic Arc and its country rocks (Oriental Terrane); d) the collisional suture, whether cryptical or not, is represented by the Central Tectonic Boundary (Figure 1).

The transitional isotopic and litogeochemical characteristics of the RNC plutonites lead to different genetic hypothesis: a) a plutonic basement of a very mature oceanic arc; b) a magmatism emplaced on thin continental crust along a passive margin. As the early subduction zone had its dip to the east, the passive margin of the later hypothesis could be the margin of a microplate (Serra do Mar Microplate (?), Campos Neto and Figueiredo 1995) or the West Congo / Angola Craton continental margin.

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