LITHOGEOCHEMISTRY OF PALEOPROTEROZOIC ORTHOGRANULITES FROM THE RIO PRETO (MG)-VASSOURAS (RJ) REGION, CENTRAL RIBEIRA BELT, SE BRAZIL

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RESUMO LITOGEOQUÍMICA DOS ORTOGRANULITOS DO COMPLEXO JUIZ DE FORA NA SEÇÃO TRANSVERSAL BOM JARDIM DE MINAS (MG)-VASSOURAS (RJ), SEGMENTO CENTRAL DA FAIXA RIBEIRA As rochas granulíticas do Complexo Juiz de Fora integram o embasamento pré-1.8 Ga da escama tectônica Média do segmento Central da Faixa Ribeira. Este domínio é marcado pela interdigitação tectônica de granulitos com unidades metassedimentares meso a neoproterozóicas. O Complexo Juiz de Fora é representado, na região entre Rio Preto (MG) e Vassouras (RJ), por três conjuntos litológicos: ortogranulitos, ortogneisses e paraganulitos, que afloram em diversas escamas de empurrão relacionadas ao encurtamento da Orogênese Brasileira. Os contatos tectônicos principais são caracterizados pela transformação dos granulitos em milonitos retrometamórficos para a fácies anfibolito. A investigação geoquímica dos ortogranulitos permitiu subdividi-los em duas associações tectônicas distintas: a) uma representada por duas séries cálcio-alcálinas geoquimicamente semelhantes às de arcos magmáticos modernos; b) outra com dois grupos de rochas básicas, um toleítico e outro com basaltos transicionais alcalinos, ambos indicando ambiente distensivo intracontinental. A relação entre estes ambientes tectônicos distintos deve ser investigada em termos geocronológicos, já que a tectônica Brasileira obliterou a paleogeografia deste importante segmento paleoproterozóico da faixa Ribeira.

Palavras chave: embasamento paleoproterozóico, margem continental ativa, magmatismo intraplaca, granulitos, Complexo Juiz de Fora

ABSTRACT The granulites of the Juiz de Fora Complex (JFC) integrate the pre-1.8 Ga basement of the Intermediate Thrust Sheet of the Ribeira Belt's central segment. This tectonic domain is characterized by intense tectonic imbrication of the JFC granulites with Meso- to Neoproterozoic metasedimentary units. In the Rio Preto (MG)-Vassouras (RJ) region, the JFC comprises three lithological associations: orthogranulites, orthogneisses and paraganulites which crop out as several thrust sheets formed by intense shortening during the Brasiliano Orogeny. The main contacts are characterized by the transformation of the granulites into amphibolite facies mylonites. The geochemistry of the orthogranulites leads to the identification of two tectonic associations. One comprises two calc-alkaline series compositionally similar to rocks of modern magmatic arcs, while the other contains two groups of basic rocks, respectively the tholeiitic series and alkaline to transitional basalts, both of intraplate extensional tectonic setting. The relationships between these distinct tectonic environments need further geochronological background, as the Brasiliano shortening obliterated the original paleogeography of this important Paleoproterozoic segment of the Ribeira belt.

Keywords: Paleoproterozoic basement, Continental active margin; Continental intraplate magmatism, Granulites, Juiz de Fora Complex

INTRODUCTION AND TECTONIC SETTING

The geochemical investigation of high grade metamorphic complexes, such as the Juiz de Fora Complex (JFC), provides key information on protoliths and their tectonic setting, as the primary textures and original relationships between different rock associations were destroyed by the intense deformation and high temperature metamorphism. Geologic investigation of granulite terranes also provides important inferences on the composition and processes of deeper segments of the continental crust. This paper presents and discusses geological and geochemical data from granulites of the JFC, an important segment of the pre-1.8 Ga basement of the Central Segment of Ribeira Belt (Fig. 1) that was reworked during the Brasiliano Orogeny.

The term Juiz de Fora Series (Ebert 1957, 1968, Cordani *et al* 1973) was originally used to designate metasediment-derived granulites exposed in the central segment of Ribeira belt. Later, orthogranulites were also included in the JFC (Barbosa & Sad 1983a, b, Machado Filho *et al* 1983, Oliveira 1980). U/Pb and Rb/Sr isotopic data indicate that the granulite facies metamorphism took place during the Paleoproterozoic Transamazonian Orogeny, further retrograded to amphibolite facies during the Neoproterozoic Brasiliano Orogeny (Cordani *et al* 1973, Machado Filho *et al* 1983, Teixeira & Figueiredo 1991). The suggestion that the JFC protoliths may be Archaean (Fyfe & Leonardos 1974, Cordani *et al*, in

Fonseca *et al* 1979, Oliveira 1980) completes the evolution scheme proposed for this complex.

GEOLOGICAL CONTEXT OF JUIZ DE FORA COMPLEX IN THE INVESTIGATED TRANSECT

Detailed geologic mapping in the Bom Jardim de Minas (MG)-Pirai (RJ) Rio Preto (MG)-Vassouras (RJ) section allowed the subdivision of the JFC into four lithologic units (Heilbron 1993): (a) orthogranulites, with amphibolite facies retrogressive mylonitic parageneses; (b) banded orthogneisses of amphibolite facies; (c) metasedimentary granulites (kinzigites with minor orthopyroxene in leucosomes); and (d) amphibolite facies metasedimentary gneisses. In this paper and based on structural-metamorphic data combined with new U/Pb geochronological data (Machado *et al* 1996), we assume that the paragneisses represent Meso to Neoproterozoic units, correlated to the Andrelândia Depositional Cycle (Andreis *et al* 1989). They were technically imbricated with the Paleoproterozoic orthogranulites and orthogneisses of the JFC during the Brasiliano orogeny. Thus, the JFC comprises the granulite facies basement (Pre-1.8 Ga) of the central segment of Ribeira belt. One U/Pb discordia (Machado *et al* 1996) and Rb/Sr errorchrons (Heilbron 1993) support the Paleoproterozoic age of the granulite facies metamorphism in the investigated region.

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Figure 1 - (a) - Simplified tectonic map of southeastern Brazil, compiled and integrated from Hasui & Oliveira (1984), Campos Neto (1992), Valeriano (1992), and Trouw & Castro (1996). The inset shows the location of the central segment of Ribeira Belt. Legend: 1- Phanerozoic cover, a -Parana basin; b, c, d and e - Taubate, Resende, Volta Redonda and Guanabara rifts; 2- Bambui Group, 3 -cratonic basement, 4 -Brasiliano fold belts (ARGD- Alto Rio Grande Domain); 5 - Guaxupe nappe; 6 - Limit of the São Francisco Craton. (b) - Tectonic compartments of the central segment of Ribeira Fold Belt (Heilbron 1993,1995). Legend: 1- São Francisco craton; 2 - autochthonous domain; 3 - lower domain; 4 - intermediate domain; 5 - upper domain; 6 - Meso-Cenozoic alkaline rocks; 7 - Phanerozoic cover; 8 -Major thrust shear zones; 9 - Major late deformation axial traces; 10 - brittle phanerozoic faults; 11 - Towns (SJ- São João del Rei, AN- Andrelândia, BP- Barra do Piraí); 12-Location of the investigated transect of figure 2.

Figure 1 - (a) - Mapa tectônico simplificado da região sudeste brasileira, compilado e integrado de Hasui & Oliveira (1984), Campos Neto (1992), Valeriano (1992) e Trouw & Castro. (1996). O paralelogramo localiza o segmento central da Faixa Ribeira. Legenda: 1 - Cobertura fanerozoica, a - Bacia do Paraná; de d a f, respectivamente, *rifts* de Taubaté, Resende, Volta Redonda e da Guanabara; 2 - Grupo Bambuí; 3 - Embasamento cratônico; 4 - Faixas dobradas brasileiras (ARGD - Domínio Alto Rio Grande); 5 - Nappe Guaxupé; 6 - Limite do Cráton do São Francisco. (b) - Compartimentação tectônica do segmento central da Faixa Ribeira (Heilbron 1993,1995). Legenda: 1 - Cráton do São Francisco; 2 - Domínio Autóctone; 3 - Domínio Inferior; 4 - Domínio Médio; 5 - Domínio Superior; 6 - Rochas alcalinas meso-cenozoicas; 7 - Cobertura fanerozoica; 8 - Principais empurrões; 9 - Principais traços axiais do redobramento tardio; 10 - Falhas rúpteis fanerozoicas; 11 - Cidades (SJ- São João del Rei, NA - Andrelândia, BP - Barra do Piraí); 12 - Área investigada em detalhe, apresentada na figura 2.

Figure 2 shows that the orthogneisses of the JFC crop out as three major tectonic thrust sheets. Their contacts are important shear zones, characterized by retrogressive amphibolite facies mylonitic textures and tectonic mixing with the Meso to Neoproterozoic cover. Within the thrust sheets, coarse granoblastic textures with green feldspars predominate.

Along the transect, granulites with intermediate composition are the most abundant rocks of the JFC, but many visited outcrops show acidic and basic types, except at the basal section of the upper granulite thrust sheet (Fig. 2), which consists of basic tholeiitic rocks. Locally, granulites display relict migmatitic structures.

Ortho and clinopyroxene, hornblende, quartz and antiperthitic plagioclase are major minerals of the orthogneisses, with minor garnet and biotite. K-feldspar is restricted to the acid terms (Table 1). Zircon, apatite, monazite, and ilmenite are accessories. Retrogressive reactions, such as hornblende and biotite rims and lamellae around and within the pyroxene crystals are common, mainly along major Brasiliano shear

zones, where the granulites are transformed into banded mylonite-gneisses.

The JFC orthogneisses (Fig. 2) are deformed acid to basic igneous rocks metamorphosed under amphibolite facies. The geochemistry of these orthogneisses will not be considered in this paper, but they probably represent the igneous protoliths of the granulites.

The paragneisses of the JFC (Fig. 2) are kinzigites with orthopyroxene-bearing leucosomes. They also occur in the studied transect, but are restricted to the basal thrust sheet (Fig. 2). Eastwards, nearby the city of Juiz de Fora, the paragneisses of the JFC become more abundant (Duarte *et al.* 1994). The kinzigites are made up of garnet, sillimanite, biotite, plagioclase, quartz, and minor K-feldspar and orthopyroxene.

GEOCHEMISTRY Previous results Oliveira (1980,1982) presented geochemical data of the JFC rocks and concluded that these rocks belong to differentiated calc-

Figure 2 - Detailed geological map of the Rio Preto (MG) - Vassouras (RJ) region, with the location of the analysed granulite samples. Legend: 1 - S-type Brasiliano granitoids; 2 - I-type Brasiliano granitoids; 3 - Andrelândia depositional cycle discriminating major quartzite layers; 4 - Mantiqueira complex; 5 - Paragranulites of JFC (?); 6 - Orthogranulites of JFC; 7 - Hornblende orthogneisses of JFC; 8 - Paraíba do Sul group or complex; 9 - Quirino complex; 10 - Major thrust shear-zones limiting the Lower, Intermediate and Upper tectonic domains; 11 - Subordinated thrusts; 12 - Subvertical faults; 13 - Sample location; 14 - Normal faults; 15 - Resende basin.

Figura 2 - Mapa geológico detalhado da Região entre Rio Preto (MG) e Vassouras (RJ), com a localização das amostras estudadas. Legenda - 1 - Granitóides brasileiros tipo-S; 2 - Granitóides brasileiros Tipo-I; 3 - Ciclo Depositional Andrelândia com bancos quartzíticos individualizados; 4 - Complexo Mantiqueira; 5 - Paragranulitos do CJF (?); 6 - Ortogranulitos do CJF; 7 - Hornblenda ortogneisses do CJF; 8 - Complexo Paraíba do Sul; 9 - Complexo Quirino; 10 - Principais empurrões basais dos domínios tectônicos Médio e Superior; 11 - Empurrões subordinados; 12 - Falhas subverticais; 13 - Localização das amostras; 14 - Falhas normais e 15 - Bacia de Resende

alkaline series, with depletion of Rb and slight enrichment of Zr, Sr and Ba as compared to the average upper crust composition. The author also proposed that the granulites represent an alkali depleted residue of extensive anatexis.

Machado Filho *et al.* (1983) subdivided the JFC into ortho- and paragranulites, the former belonging both to the calc-alkaline and tholeiitic series. The calc-alkaline orthogranulites was interpreted as representing lower crust samples, while the tholeiitic granulites were correlated to an Archean basaltic crust. The calc-alkaline and tholeiitic nature of the JFC granulites were also recognized by Barbosa & Sad (1983 a, b) and Sad & Barbosa (1985). The authors suggest that the calc-alkaline granulites may represent either metasedimentary rocks or injection of an acid magma within the basic rocks, while the tholeiitic samples characterize a mafic oceanic crust.

Figueiredo & Campos Neto (1993) and Campos Neto & Figueiredo (1990) discuss geochemical data of the northern segment of the JFC in the Rio de Janeiro state, and describe the occurrence of Orthogranulites (Itaperuna-Comendador Venancio unit) and amphibolite facies orthogneisses (São João do Paraíso unit) with calc-silicate inclusions. The analytical data of both units are similar and indicate two calc-

alkaline series. One is represented by a large compositional variety of rocks, enriched in Mg, Ca and Cr, and with slightly fractionated chondrite REE normalized patterns. The other is enriched in LILE, with higher Fe, Ti, K, Rb, Ba, Nb, Zr and HREE contents, and more fractionated chondrite normalized REE patterns with negative Eu anomaly.

Sampling Based on field and petrographic data (Table 1), 37 samples of granulites were selected for chemical analyses. The location of the sampled outcrops is shown in figure 2. The analyses were performed at Geosol-Geolab Division Laboratory, Brazil. Si, Al, Ti, Ca, Fe^{tot}, P, and trace elements were analysed by XRF, while Mn, Ca, Na, K, and Mg by atomic absorption, Fe²⁺ by wet chemical analysis, and REE by fusion-ICP. The analytical results are in Tables 2 to 4.

Chemical discrimination and tectonic settings The studied granulites subdivide into two groups of acid to intermediate composition (Table 2 and 3) and two groups of basic composition (Table 4).

ACID TO INTERMEDIATE GRANULITES These granulites comprise two geochemical groups, named CAS1

Table 1- Simplified mineralogy of the granulites of the Juiz de Fora Complex, subdivided into distinctive geochemical groups. Mineral abbreviations: OPX- orthopyroxene; CPX-clinopyroxene; HBL- hornblende; BIO- biotite; PLAG-plagioclase; QZ- quartz; KF- alkali-feldspar; ZIR- zircon; AP- apatite; GAR- garnet; OP- opaque minerals

Tabela 1- Mineralogia simplificada dos granulitos do Complexo Juiz de Fora, subdivididos pelos diferentes grupos geoquímicos.

Group	Sample	Rock type	Mineralogy
CAS1	BP-CM 150e; RPM-555; BP-CM-153b; VAL-M-276; BP-CM-231; NSA-5-9a; BP-CM-142; VAL-I-12; NSA-5-8; VAL-IV-23	Intermediate	OPX; HBL; BIO; PLAG; QZ; ZIR; AP; OP
	RPM-546; RPM-193e; VAL-593	Acid	OPX; HBL; BIO; PLAG; QZ; KF; ZIR; OP
CAS2	VAL-511a; BP-CM-148; VAL-III-11	Intermediate	OPX
	RPM-344e; RPM-565a; RPM-570; BP-CM-150a; NSA-5-9c; CJE-44-7; VAL-IV-99	Acid	OPX; BIO; KF; PLAG; QZ; ZIR; OP; GAR
B1	CPH-118	Ultrabasic	CPX; HBL; OP; PLAG
	NSA-CM-94; BP-CM-151; RPM-520b; RPM-534; VAL-M-503a; VAL-M-503b; BP-CM-166b	Basic	CPX; OPX; HBL; BIO; PLAG; QZ; ZIR; AP
B2	CJE-44-1; CJE-44-11; CON-204; NSA-5-9d	Basic	CPX; OPX; HBL; BIO; PLAG; QZ; ZIR; AP
	CJE-44-6b	Intermediate	OPX; PLAG; QZ; ZIR; OP

and CAS2, which probably belong to different calc-alkaline series (Figs. 3a and 3b). They are metaluminous rocks with Shand's index below 1 (Fig. 3c). Their chemical composition classification, also corroborated by petrographic data, indicate the predominance of intermediate (enderbitic) rocks, as shown in the Alk x SiO₂ diagram of Le Maitre (1989) and in the Middlemost (1985) diagram (Figs. 3d and 3e), and by the QAP normative diagram (Fig. 3f).

The CAS1 samples belong to a medium-K calc-alkaline series (open circles in all diagrams). It is the most expanded series and includes gabbrodiorite, diorite, tonalite, granodiorite and one granite sample (Figs. 3d to 3f). As compared to the CAS2 series (open squares), discussed below, the CAS1 is relatively enriched in compatible elements (CaO, MgO, FeO*, MnO, Cr), and HFS elements (e.g. TiO₂, P₂O₅), as shown respectively in figures 4a and 4b. In spite of the LILE scatter relative to SiO₂ (Fig. 4c), probably due to metamorphic remobilization during the Brasiliano Cycle, the CAS1 samples generally have lower contents in these elements. REE normalized to chondrite are more enriched but less fractionated than the CAS2 (Figs. 5a, 5b), show large negative Eu anomalies (Eu/Eu* between 0.35 and 0.80), and the HREE content decreases with differentiation (Fig. 5a). The CAS1 rocks also show the lowest Rb/Sr and the highest Sm/Nd ratios. Two samples (VAL-IV-23, VAL-593), represented by half-filled circles in the Harker diagrams (Figs. 4a to 4c), have some chemical similarities with CAS 1, but their chondrite normalized REE pattern is more fractionated, lack negative Eu anomaly (Eu/Eu* ≈ 1), and have higher Cr contents.

The CAS2 samples (open squares) belong to a high-K calc-alkaline series, with granites, and minor granodiorites and monzodiorites, containing up to 4.1% K₂O (Fig. 3d to 3f). As compared to the CAS1, the CAS2 samples are depleted in HFSE and particularly in compatible elements, except Ni (Fig. 4a, b). This group is also enriched in LILE, especially K₂O, Rb and Sr (Fig. 4c), and is richer in Al₂O₃. Chondrite-normalized REE abundances display higher fractionation (Fig. 5c), with substantial depletion in HREE and positive Eu anomalies (Eu/Eu* up to 1.4). This group also has higher K/Rb, Rb/Sr, K/Ba, and La/Sm ratios, consistent with the LILE enrichment. U/Pb data on zircons from acid granulites of outcrop 44, located near the town of Conser-vatória (Fig. 2), define a discordia with intercepts at 2134 and

579 Ma, while monazite from the same sample is concordant at 563 Ma (Machado *et al.* 1996). Field relationships indicate that CAS2 is intrusive in CAS 1 and B2 basic group (described below), which also integrate the JFC.

Three samples (half-filled squares) show enrichment in LREE (Fig. 5d) and highly fractionated REE chondrite-normalized signature. When compared with the rest of CAS2 samples, they also display enrichment in some HFS elements (e.g. Y, Zr, P₂O₅), and in Ba and Cr, and have very low Ni contents (Figs. 4a, 4b and 4c). Due to the small number of samples, the distinct chemical composition of three samples might be due either to a distinct calc-alkaline group or to magmatic differentiation.

The plot of the CAS1 and CAS2 samples in tectonic discrimination diagrams, such as Rb x Y+Nb (Pearce *et al.* 1984) suggest a volcanic arc setting (Fig. 6). The R1 x R2 (Batchelor & Bowden 1985) diagram suggests that the CAS1 rocks may have been derived from pre-collisional granitoids, while the CAS 2 rocks represent late- to post-collisional granitoids (Fig. 7). The K₂O x SiO₂ diagram (le Maitre 1989) and the log CaO/Alk x SiO₂ diagram (Brown 1982), not shown in this paper, are also suggestive of a progressive chemical maturity from the CAS1 to the CAS2 group, as observed in modern compressive settings, with enrichment in Alk and in the total LILE. The multielemental diagrams such as the Ocean Ridge Granite normalized spidergrams (Fig. 8) of Pearce *et al.* (1984), are also consistent with magmatic arc settings.

Sample CJE-44-6b (asterisk) is a leucosome associated with alkaline to transitional basic rocks of B2 group (see below). As the other samples of this group, it shows very high contents of HFS elements.

BASIC GRANULITES The basic rocks of the JFC (Table 4) show some compositional dispersion, even within a small number of samples. They are tentatively subdivided in two groups.

The **B1 group** (triangles) is characterized by low-TiO₂ - P₂O₅ tholeiitic basic rocks (Figs. 9 to 12) and one ultrabasic sample (CPH-118). The basic samples classify as olivine gabbros, norites, and gabbro-diorites in the R1R2 diagram (not shown). The chemical classification of Jensen (1976) (Fig. 11) and the binary variation diagrams (Figs. 12a and 12b) indicate that two of the tholeiitic basic samples (inverted

Table 2- Geochemical data of acid to intermediate granulites of JFC: Data of CASI group. Underlined values represent the detection limit of the laboratory

Tabela 2- Dados geoquímicos de granulitos ácidos a intermediários do JFC: Análises do grupo CASI. Os valores sublinhados representam o limite de detecção do laboratório.

Sample	CASI												
	BP-CM-150E	RPM-555	BP-CM-153B	VAL-M-276	BP-CM-231	NSA-5-9A	BP-CM-142	VAL I 12	NSA-5-8	RPM-546	RPM-193E	VAL IV 23	VAL 593
SiO ₂	57.10	57.60	57.90	58.00	58.80	59.10	61.80	61.60	61.30	62.90	65.10	52.30	66.80
TiO ₂	0.58	0.83	0.89	0.87	0.75	0.86	1.00	0.65	0.70	0.83	0.45	0.92	0.34
Al ₂ O ₃	14.30	15.80	16.70	15.80	15.70	15.80	15.20	15.30	17.00	14.70	14.80	16.00	14.80
Fe ₂ O ₃	0.98	2.10	1.10	5.00	3.30	1.40	2.00	2.96	0.58	1.50	1.10	3.36	1.40
FeO	7.40	6.60	7.00	3.20	4.60	5.80	5.20	4.40	5.20	5.00	3.10	6.70	3.00
MnO	0.22	0.25	0.18	0.15	0.15	0.15	0.15	0.16	0.15	0.11	0.08	0.19	0.11
MgO	5.70	3.90	3.40	3.60	3.30	3.60	1.80	3.50	2.90	2.50	2.40	7.40	2.30
CaO	7.90	5.00	6.20	6.30	6.10	5.30	4.80	4.90	5.10	3.90	2.70	7.40	4.00
Na ₂ O	4.20	3.80	4.50	4.00	4.30	4.40	5.00	3.36	3.50	4.20	3.20	2.90	3.50
K ₂ O	0.38	2.20	1.40	1.80	1.70	2.10	1.20	1.60	1.80	2.00	4.70	1.30	2.80
P ₂ O ₅	0.05	0.61	0.33	0.20	0.24	0.32	0.33	0.16	0.30	0.20	0.14	0.15	0.12
H ₂ O	0.45	0.73	0.41	0.51	0.47	0.63	0.54	-	0.81	0.74	0.70	-	-
CO ₂	0.55	0.40	0.25	0.25	0.25	0.40	0.80	-	0.40	1.00	1.30	-	-
LOI	0.22	0.01	0.11	0.03	0.03	0.14	0.16	0.52	0.10	0.04	0.09	0.01	0.29
Total	100.03	99.83	100.37	99.71	99.69	99.37	99.98	99.11	99.84	99.62	99.86	98.63	99.46
Mg #	55.09	45.01	43.13	45.45	43.72	47.61	31.42	46.89	47.46	41.23	51.12	57.56	49.04
Cr	120	-	79	-	-	100	23	109	59	-	-	342	68
Ni	71	-	56	-	-	62	55	24	55	-	-	41	24
Co	-	46	-	87	51	-	-	-	-	41	46	-	-
V	-	98	-	120	130	-	-	-	-	130	72	-	-
K	3154	18263	11622	14942	14112	17433	9962	-	14942	16603	39016	-	-
Rb	12	94	29	15	34	87	18	77	91	100	190	41	70
Cs	-	-	-	-	-	-	-	5.00	-	-	-	5.00	5.00
Ba	280	358	620	421	1254	880	730	389	660	546	896	403	2006
Sr	270	290	600	300	600	530	490	390	500	350	350	236	506
Ta	-	-	-	-	-	-	-	5.00	-	-	-	5.00	11.00
Nb	<u>10</u>	17	12	<u>10</u>	12	18	<u>10</u>	8	12	13	19	5	8
Hf	-	-	-	-	-	-	-	8.00	-	-	-	8.00	8.00
Zr	47	240	190	75	180	200	120	145	140	190	250	129	170
Ti	3477	4976	5336	5216	4496	5156	5995	-	4197	4976	2698	-	-
Y	<u>≤10</u>	51	20	42	24	42	14	30	39	22	18	25	22
Th	-	-	-	-	-	-	-	8.00	-	-	-	5.00	5.00
U	-	-	-	-	-	-	-	10.00	-	-	-	12.00	12.00
La	-	22.48	-	31.40	23.38	-	-	76.87	-	38.21	26.85	18.38	15.69
Ce	-	60.28	-	75.26	55.50	-	-	136.80	-	86.60	57.38	41.48	33.51
Nd	-	34.08	-	35.09	27.50	-	-	59.27	-	35.64	24.32	15.46	12.66
Sm	-	7.76	-	6.77	5.20	-	-	9.50	-	5.84	4.79	3.26	2.36
Eu	-	0.89	-	1.23	1.19	-	-	0.99	-	0.74	0.85	0.87	0.70
Gd	-	6.75	-	5.09	3.86	-	-	5.55	-	4.30	3.61	2.47	1.90
Dy	-	6.75	-	4.36	2.99	-	-	4.28	-	2.87	2.14	2.23	1.78
Ho	-	1.48	-	0.92	0.62	-	-	0.80	-	0.61	0.42	0.37	0.36
Er	-	3.92	-	2.69	1.72	-	-	1.84	-	1.60	1.07	0.94	0.98
Yb	-	3.27	-	2.43	1.51	-	-	1.32	-	1.27	0.68	0.74	0.77
Lu	-	0.42	-	0.34	0.21	-	-	0.15	-	0.18	0.12	0.09	0.11

Table 3- Geochemical data of acid to intermediate granulites: Data of CAS2 group (squares symbols). The three samples at the right side of the table belong to the subgroup represented as partial filled squares. Underlined values represent the detection limit of the laboratory

Tabela 3- Dados geoquímicos de granulitos dados a intermediários: Análises do grupo CAS2 (símbolos : quadrados). As tres amostras localizadas no lado direito da tabela pertencem ao subgrupo representado por quadrados parcialmente preenchidos. Os valores sublinhados representam o limite de detecção do laboratório.

	CSA2								CAS2 LREE enriched			B2
Sample	VAL-M-511A	RPM-344E	RPM-565A	RPM-570	BP-CM-150A	NSA-5-9B	NSA-5-9C	CJE-44-7	BP-CM-148	VAL III 11	VAL IV 99	CJE-44-6b
SiO ₂	58.10	65.00	70.50	70.70	71.00	74.60	74.70	76.20	53.50	59.60	66.50	55.70
TiO ₂	0.82	0.42	0.19	0.50	0.36	0.40	0.24	0.13	1.50	0.67	0.26	2.10
Al ₂ O ₃	18.10	15.60	13.90	13.90	15.40	11.80	12.60	12.00	17.20	17.00	16.40	15.40
Fe ₂ O ₃	1.30	1.20	0.64	0.84	0.63	0.81	0.29	0.95	1.10	2.20	1.10	3.00
FeO	4.80	2.90	1.40	1.40	0.87	0.98	1.01	0.14	6.80	4.60	2.00	7.10
MnO	0.09	0.06	0.04	0.04	0.05	0.05	0.05	0.02	0.22	0.10	0.01	0.22
MgO	2.90	2.00	0.77	1.50	0.14	0.31	0.20	0.12	3.80	3.60	1.80	2.40
CaO	5.40	2.30	2.30	2.20	1.80	1.70	1.00	1.10	5.70	3.20	2.80	5.50
Na ₂ O	5.20	3.40	3.30	3.60	4.60	3.50	3.00	3.30	4.10	3.50	4.10	5.80
K ₂ O	1.90	6.20	5.80	3.70	4.30	3.70	5.90	5.10	2.30	4.10	4.00	1.10
P ₂ O ₅	0.29	0.13	0.07	0.13	0.09	0.05	0.05	0.06	1.20	0.28	0.15	0.54
H ₂ O	0.55	0.24	0.28	0.48	0.42	1.21	0.59	0.42	1.56	-	-	0.64
CO ₂	0.40	0.25	0.40	0.75	0.20	0.80	0.25	0.25	0.70	-	-	0.45
LOI	0.02	0.02	0.03	0.06	0.16	0.07	0.12	0.37	0.16	0.29	0.40	0.40
Total	99.87	99.72	99.62	99.80	100.02	99.98	100.00	100.16	99.84	99.14	99.52	100.35
Mg #	46.40	47.24	40.98	55.35	14.79	24.43	21.90	17.69	46.50	49.37	51.76	30.38
Cr	-	-	-	-	5	-	5	5	80	48	41	18
Ni	-	-	-	-	50	-	47	47	73	24	24	55
Co	46	36	21	26	-	31	-	-	-	-	-	-
V	120	72	20	57	-	10	-	-	-	-	-	-
K	15772	51468	48148	30715	35696	30715	48978	42337	19093	-	33205	9131
Rb	51	160	140	120	160	96	120	100	48	125	102	18
Cs	-	-	-	-	-	-	-	-	-	5.00	5.00	-
Ba	896	1970	1433	1075	840	896	1400	1100	1610	1863	1263	160
Sr	930	520	480	390	290	150	170	140	710	517	645	170
Ta	-	-	-	-	-	-	-	-	-	5.00	5.00	-
Nb	<u>10</u>	12	<u>10</u>	11	14	15	<u>10</u>	<u>10</u>	18	11	7	48
Hf	-	-	-	-	-	-	-	-	-	8.00	8.00	-
Zr	140	160	130	300	260	330	140	170	280	185	275	110
Ti	4916	2518	1139	2998	2158	2398	1439	779	8993	-	1559	12589
Y	<u>10</u>	<u>10</u>	<u>10</u>	<u>10</u>	42	<u>10</u>	15	11	25	11	16	13
Th	-	-	-	-	-	-	-	-	-	5.00	72.00	-
U	-	-	-	-	-	-	-	-	-	10.00	10.00	-
La	19.45	15.36	15.60	16.93	-	5.33	-	51.46	-	35.14	126.20	29.06
Ce	45.59	33.04	26.23	35.23	-	12.05	-	100.60	-	75.08	246.50	71.34
Nd	20.93	14.42	9.11	13.15	-	5.23	-	34.66	-	29.27	64.13	39.90
Sm	3.22	2.48	1.48	1.92	-	1.09	-	3.89	-	4.61	8.53	7.97
Eu	1.14	0.99	0.77	0.73	-	0.52	-	1.35	-	1.06	1.12	1.63
Gd	1.94	1.84	1.09	1.16	-	0.93	-	1.97	-	2.54	3.38	6.49
Dy	1.03	1.03	0.79	0.75	-	0.44	-	0.97	-	1.39	1.71	5.35
Ho	0.17	0.19	0.19	0.14	-	0.08	-	0.14	-	0.18	0.27	.96
Er	0.43	0.48	0.63	0.36	-	0.21	-	0.29	-	0.40	0.49	2.29
Yb	0.31	0.42	0.46	0.23	-	0.17	-	0.26	-	0.20	0.24	1.65
Lu	0.06	0.10	0.08	0.04	-	0.06	-	0.06	-	0.03	0.03	0.23

Table 4- Geochemical data of basic and ultrabasic granulitic rocks. Underlined values represent the detection limit of the laboratory

Tabela 4- Dados geoquímicos dos granulitos básicos e ultrabásicos do JFC. Os valores sublinhados representam o limite de detecção do laboratório.

Sample	GROUP B1								GROUP B2				VAL I 94
	CPH 118	NSAC M 94	BPCM 151	RPM- 520-B	RPM- 534	VAL-M- 503A	VAL-M- 503-	BP-CM- 166B	CJE-44- 1	CJE-44- 11	CON- 204	NSA-5- 9D	
SiO ₂	38.40	49.90	51.10	49.00	49.20	49.80	49.30	50.00	47.80	48.00	48.70	48.70	49.90
TiO ₂	1.80	0.88	0.59	1.50	1.40	1.80	1.80	1.80	3.50	3.50	4.50	3.30	1.20
Al ₂ O ₃	12.20	15.10	13.20	15.00	14.60	13.80	13.40	14.20	12.70	12.40	14.30	12.90	18.30
Fe ₂ O ₃	11.80	2.10	1.80	4.70	2.90	4.30	5.50	1.30	9.10	6.70	1.50	5.80	2.50
FeO	8.70	8.00	8.40	7.80	9.10	9.80	9.80	12.50	7.10	10.00	10.40	10.10	9.50
MnO	0.21	0.21	0.22	0.20	0.20	0.21	0.21	0.28	0.28	0.27	0.23	0.29	0.28
MgO	11.40	8.70	8.40	6.30	6.80	5.60	5.50	5.50	3.90	3.70	3.90	4.10	7.00
CaO	12.90	11.40	11.60	11.60	11.80	9.30	9.10	10.10	8.40	8.10	8.60	6.90	7.80
Na ₂ O	0.87	1.80	2.80	2.40	2.50	3.30	3.20	2.90	4.00	4.10	2.70	4.10	1.20
K ₂ O	0.13	0.58	0.48	0.19	0.16	0.86	0.83	0.33	1.40	1.40	1.70	1.40	0.63
P ₂ O ₅	0.13	0.06	0.05	0.11	0.12	0.24	0.23	0.23	0.70	0.73	2.10	0.58	0.09
H ₂ O	0.89	0.89	0.34	0.76	0.53	0.30	0.45	0.48	0.48	0.55	0.72	0.67	-
CO ₂	0.25	0.25	0.45	0.25	0.55	0.40	0.40	0.25	0.45	0.25	0.25	0.80	-
LOI	0.06	0.08	0.10	0.02	0.02	-	0.05	0.09	0.35	0.33	0.16	0.08	0.44
Total	99.44	99.95	99.53	99.83	99.88	99.71	99.77	99.96	100.16	100.03	99.76	99.72	98.84
Mg #	51.26	61.05	59.90	48.27	50.86	42.20	39.92	41.76	31.25	29.15	37.17	32.29	51.50
Cr	-	320	450	-	-	-	-	210	37	33	11	-	192
Ni	-	110	140	-	-	-	-	71	61	56	49	-	24
Co	123	-	-	72	72	77	77	-	-	-	-	72	-
V	290	-	-	320	300	290	280	-	-	-	-	280	-
K	1079	4815	3985	1577	1328	7139	6890	2739	11622	11622	14112	11622	-
Rb	5	13	12	9	8	19	19	12	22	20	37	20	28
Cs	-	-	-	-	-	-	-	-	-	-	-	-	5.00
Ba	45	20	100	72	72	493	493	20	370	390	570	412	196
Sr	160	150	120	180	140	210	190	130	110	130	430	97	194
Ta	-	-	-	-	-	-	-	-	-	-	-	-	5.00
Nb	11	<u>10</u>	<u>10</u>	<u>10</u>	<u>10</u>	<u>10</u>	14	<u>10</u>	43	33	25	93	20
Hf	-	-	-	-	-	-	-	-	-	-	-	-	8.00
Zr	68	37	30	83	79	170	160	100	230	300	140	270	129
Ti	10791	5276	3537	8993	8393	10791	10791	10791	20983	20983	26978	19784	-
Y	17	<u>10</u>	<u>10</u>	19	21	33	32	16	50	49	32	140	7
Th	-	-	-	-	-	-	-	-	-	-	-	-	5.00
U	-	-	-	-	-	-	-	-	-	-	-	-	12.00
La	13.50	-	-	5.72	5.91	18.14	16.15	-	32.96	37.85	-	30.95	14.00
Ce	34.43	-	-	16.91	16.84	42.05	40.22	-	87.15	94.80	-	90.69	28.69
Nd	16.74	-	-	11.24	10.74	22.19	20.75	-	54.34	56.77	-	61.92	9.43
Sm	3.57	-	-	3.04	2.86	5.04	4.66	-	13.68	12.51	-	16.65	1.63
Eu	0.76	-	-	0.88	0.80	1.28	1.17	-	2.19	2.89	-	1.94	0.86
Gd	3.11	-	-	3.08	2.87	4.65	4.22	-	13.87	11.32	-	16.96	1.17
Dy	2.70	-	-	3.17	2.86	4.96	4.29	-	13.74	12.61	-	22.97	1.04
Ho	0.60	-	-	0.64	0.60	1.04	0.93	-	2.79	2.64	-	4.50	0.23
Er	1.91	-	-	1.77	1.76	3.04	2.84	-	6.47	7.14	-	11.62	0.71
Yb	1.51	-	-	1.38	1.39	2.63	2.50	-	7.10	6.72	-	8.86	0.68
Lu	0.20	-	-	0.19	0.20	0.33	0.34	-	1.00	0.96	-	0.98	0.10

triangles) are less differentiated, enriched in MgO and MnO, with higher Mg # (Table 4). The two samples also display relative enrichment and/or remobilization of some LILE, such as K₂O, Na₂O and Ba. The other samples of the B1

tholeiitic basic rocks (triangles) are progressively enriched in incompatible elements (Fig. 12a, b), probably indicating higher degree of differentiation and/or crustal contamination. The chondrite normalized REE abundances of B1 group are

Figure 3 - (a) - Plot of acid to intermediate granulites in the Alk x SiO₂ diagram of Irvine & Baragar (1971). (b) - AFM diagram (Irvine & Baragar 1971) with the distribution of the calc-alkaline series, (c) - Metaluminous character of the two calc-alkaline series (Maniar & Piccoli 1989). (d) - Plot of the calc-alkaline series within the Alk x SiO₂ chemical classification diagram (Le Maitre 1989). Legend: 1 - foidite; 2 - tephrite and basanite, 3 - phono-tephrite, 4 - tephri-phonolite, 5 - phonolite, 6 - trachy-basalt, 7 - basaltic trachy-andesite, 8 - trachy-andesite, 9 - trachyte and trachy-dacite, 10 - picrobasalt, 11 - basalt, 12 - basaltic andesite, 13 - andesite, 14 - dacite, 15 - rhyolite. (e) - Plot of the calc-alkaline series within the Alk x SiO₂ chemical classification diagram (Middlemost 1985). Legend: 1 - alkali feldspar syenite, 2 - alkali feldspar quartz syenite, 3 - alkali feldspar granite, 4 - syenite, 5 - quartz syenite, 6 - granite, 7 - monzonite, 8 - quartz monzonite, 9 - monzodiorite, 10 - quartz monzodiorite, 11 - granodiorite, 12 - diorite and gabbro, 13 - quartz diorite, 14 - tonalite. (f) - QAP normative diagram for rocks of the calc-alkaline series. Symbols: CAS1 - circles and half-filled circles, CSA2 - squares and half-filled squares; Leucosome associated to B2 basic rocks - asterisk. Figura 3 - (a) - Granulitos félsicos a intermedianas no diagrama Alk x SiO₂ de Irvine & Baragar (1971). (b) - Diagrama AFM (Irvine & Baragar 1971) com a distribuição das séries cálcio-alcálinas. (c) - Caráter metaluminoso das duas séries cálcio-alcálinas no diagrama de Maniar & Piccoli (1989). (d) - As séries cálcio-alcálinas no diagrama de classificação química Alk x SiO₂ (Le Maitre 1989). (e) - Diagrama de classificação química Alk x SiO₂ de Middlemost (1985) para as rochas granulíticas intermediárias a ácidas. (f) - Diagrama QAP normativa para as rochas das séries cálcio-alcálinas. Símbolos: CAS1 - círculos e círculos parcialmente preenchidos; CAS2 - quadrados e quadrados parcialmente preenchidos; Leucossoma associado às rochas básicas do grupo B2 - asterisk.

Figure 4 - Selected bivariate diagrams for the calc-alkaline series, (a) - compatible elements, (b) - HFS elements, (c) - LILE, Al_2O_3 and Yb. Symbols as in figure 3.
 Figura 4 - Diagramas de variação para as rochas calcio-alcálinas. (a) elementos compatíveis. (b) -elementos HFS. (c) - elementos LIL, Al_2O_3 , e Yb. Símbolos como na figura 3.

Figure 5 - Chondrite-normalized (Boynton 1984) REE signature of the -alkaline series: (a) CAS1; (b) anomalous samples of CAS1, (c) CAS2, and (d) anomalous samples of CAS2

Figura 5 - Padrões de abundância dos REE normalizados por condrito (Boynton 1984) das séries calcio-alcálinas: (a) CAS1, (b) amostras anômalas das CAS1, (c) CAS2, e (d) amostras anômalas da CAS2.

Figure 6 - Plot of the calc-alkaline series within the Rb x Y+Nb tectonic discriminant diagram (Pearce et al. 1984). Legend: sin-col- sin-collisional granitoids, WPG- within plate granitoids, VAG- volcanic arc granitoids, ORG- ocean ridge granitoids. Symbols as in figure 3.

Figura 6 - Rochas calcio-alcálinas plotadas no diagrama discriminante Rb x Y+Nb (Pearce et al. 1984). Símbolos como na figura 3.

highly fractionated, and as compared to B2 group, more depleted in total REE and have a smaller negative Eu anomalies ($\text{Eu}/\text{Eu}^* \approx 0.81-0.88$) (Fig. 13).

One single ultramafic sample (filled inverted triangle) is composed only (Table 1) by clinopyroxene, green amphibole and ilmenite. In the Jensen's diagram, it classifies as a komatiitic basalt (Fig. 11), while in the le Maitre's diagram it plots

Figure 7 - R1 x R2 diagram (Batchelor & Bowden 1985) with the tectonic discrimination of the calc-alkaline series. Symbols as in figure 3.

Figura 7 - Ambientação tectônica das séries calcio-alcálinas segundo o diagrama discriminante R1 x R2 de Batchelor & Bowden (1985). Símbolos como na figura 3.

in the meimechite and komatiitic fields. However the lower content of MgO (< than komatiitic rocks), the higher contents of Fe_2O_3 , FeO , TiO_2 , CaO , V, and its mineralogy suggest cumulative processes derived from rocks of the B1 group.

The **B2 group** (asterisks) comprises alkaline to transitional high $\text{TiO}_2 - \text{P}_2\text{O}_5$ basic rocks enriched in HFS elements (Figs. 9, 12a and 12b), including sieno and monzo-gabbros (R1R2

Figure 8 - Ocean Ridge Granite (Pearce *et al.* 1984) normalized multielemental spidergrams of the calc-alkaline series. The CAS1 and CAS2 (gray shaded area) exhibit patterns similar to those of volcanic arc granitoids.

Figura 8 - Aranhogramas normalizados por Ocean Ridge Granite (Pearce *et al.* 1984) para as duas séries calcio-alcálicas CAS1 e CAS2 (área cinza), que apresentam padrões semelhantes aos granitóides de arcos vulcânicos.

Figure 9 - Classification of basic rocks in the Alk x SiO₂ diagram of Le Maitre (1989). The dashed line is the boundary between alkaline and sub-alkaline fields (Irvine & Baragar 1971). Symbols: B1 group -triangles; B2 group - asterisks, High alumina basalt -open, square, cumulitic rock - inverted filled triangle. Fields: 1 - Foidite, 2 - Tephrite and Basanite 3 -Phonotephrite, 4 -Tephriphonolite, 5 - Phonolite, 6 - Trachybasalt, 7 -Basaltic trachyandesite, 8 -Trachyandesite, 9 - Trachyte, 9 - Picrite, 11 - Basalt, 12 -Basaltic Andesite, 13 -Andesite, 14 - Dacite and 15 -Rhyolite.

Figura 9 - Classificação das rochas básicas no diagrama Alk x SiO₂ Le Maitre (1989). A linha pontilhada subdivide os campos alcalino e sub-alcálico segundo Irvine & Baragar (1971). Símbolos grupo B1- triângulos, grupo B2-asteriscos, basalto rico em alumina- quadrado, cumulado ultrabásico- triângulo preto invertido.

diagram of De La Roche *et al.* 1980, not shown). Figures 12a and 12b indicate that, in comparison with the B1 group, the B2 rocks are high TiO₂ (> 3.3%), K₂O (1.1-1.7%), FeO* (> 10%), P₂O₅ (> 0.58%), and enriched in incompatible elements, such as Rb, Zr, Ba, Nb, Y and REE. Normalized to chondrite, their REE abundance (Fig. 13) displays bulk enrichment, less fractionated patterns, flatter HREE distribution, and negative Eu anomalies (Eu/Eu* ≈ 0.74 and 0.31).

Figure 10- Plot of the basic sub-alkaline granulitic rocks in the AFM diagram. Symbols as in figure 9.

Figure 10- Diagrama AFM de Irvine & Baragar (1971) com as amostras dos granulitos básicos.sub-alcálicos Símbolos como na figura 9.

Figure 11- The cationic diagram of Jensen (1976) separates some samples of B1 group that plot within the HMT field (High MgO tholeiites) and one sample that plots in the calc-alkaline field. Symbols as in figure 9.

Figure 11- O diagrama catiônico de Jensen (1976) separa algumas rochas do grupo B1 que plotam no campo dos HMT e uma amostra que plota no campo calcio-alcálico. Símbolos como na figura 9.

One sample (Val-I-594) of a high alumina calc-alkaline gabbroic granulite (open square), has a chemical composition (Figs. 12a and 12b) and chondrite-normalized REE abundance (Fig. 13) more consistent with the CAS2 series. This association is stronger if the diagrams of figures 14a to 14d are considered.

In spite of uncertainties about the occurrence of primary liquids or differentiates and modifications due to two metamorphic pulses, the basic rocks of the Juiz de Fora complex were plotted in tectonic discriminant diagrams (Fig. 14). The B1 samples disperse in the intraplate, ocean floor and island arc fields. The more LILE-enriched samples (triangles) plot in the E-MORB and intraplate fields, while the most LILE-depleted samples plot also in the island arc basalt field.

Figure 12 - (a) - Selected binary variation diagrams for the basic groups: major elements. Symbols as in figure 14. (b) - Selected binary variation diagrams for the basic groups: selected trace elements. Symbols as in figure 9. Figura 12 - (a) - Diagramas de variação para rochas básicas: elementos maiores. Símbolos como na figura 14. (b) - Diagramas de variação para rochas básicas: elementos traços. Símbolos como na figura 9.

Figure 13- Chondrite-normalized (Boynton 1984) REE signature of the JFC basic rocks: a) B1 and B2 groups; b) cumulatic rock and calc-alkaline sample. Symbols as in figure 9.

Figura 13- Assinatura dos REE normalizados por condrito (Boynton 1984) para as rochas básicas do JFC: a) Grupos B1 e B2; b) Rocha cumulática e amostra calcio-alkalina. Símbolos como na figura 9.

Figure 14 - (a) - Plot of tholeiitic B1 group in the $2Nb \times Zr/4 \times Y$ tectonic discriminant diagram of Meschede (1986). (b) - $Zr/Y \times Zr$ tectonic discriminant diagram (Pearce & Norry 1979) for the basic granulitic rocks, (c) - $Ti/100 \times Zr \times Y$ tectonic diagram of Pearce & Cann (1973) for basic granulitic rocks of B1 group. Fields: OFB- Ocean Floor Basalts, WPB- Within Plate Basalts, LKT- Low-K Tholeiites, CAB- Calc-alkaline Basalts, (d) - Plot of basic groups of the B1 group in the $Ti/100 \times Zr \times Sr/2$ tectonic discriminant diagram of Pearce & Cann (1973). Fields: OFB- Ocean Floor Basalts, IAB- Island Arc Basalts, CAB- Calc-alkaline Basalts. Symbols as in figure 9.

Figura 14 - (a) - Rochas básicas toleíticas do grupo B1 plotadas no diagrama discriminante $2Nb \times Zr/4 \times Y$ de Meschede (1986). (b) - Rochas básicas toleíticas do grupo B1 plotadas no diagrama discriminante $Zr/Y \times Zr$ de (Pearce & Norry 1979). (c) - Rochas básicas do grupo B1 plotadas no diagrama discriminante $Ti/100 \times Zr \times Y$ de Pearce & Cann (1973). (d) - Rochas básicas do grupo B1 plotadas no diagrama discriminante $Ti/100 \times Zr \times Sr/2$ de Pearce & Cann (1973). Símbolos como na figura 9.

However, as the B1 samples occur in continuous outcrops along the base of the uppermost granulitic thrust sheet (Fig. 2), except sample 94, they can be interpreted as formed under a common tectonic setting. The multielemental N-MORB normalized diagrams (Pearce 1983) indicate that B1 samples fit equally to E-MORB, Back-arc Basalts and Within plate tholeiites (Fig. 15a). The lack of field evidences for typical ophiolite petrotextonic associations, such as ultrabasic rocks and pelitic-chert deep marine sediments, besides tholeiitic basic rocks, suggests continental intraplate environment. The B1 rocks are also compared to Phanerozoic and Proterozoic examples of continental tholeiitic intraplate magmas (Figs. 15b and 15c).

Besides the alkaline character of the B2 group rocks, indicated by the $\text{Alk} \times \text{SiO}_2$ ratios (Fig. 11), other diagrams that use P_2O_5 , TiO_2 , Zr, La and Nb contents (Winchester & Floyd 1976, Rollinson 1993, Mullen 1983, not shown), show that these rocks are enriched in HFSE and LREE, and point to intraplate settings (continental alkaline or alkaline ocean is-

land). The alkaline continental within-plate environment is also indicated by the N-MORB normalized expanded spidergrams (Pearce 1983), compared with modern examples of Ocean Island Basalts and Alkaline Continental Basalts (Fig. 15d).

FINAL REMARKS The geochemical data of the JFC in the investigated transect reveal a complex geological evolution prior to the Brasiliano orogeny. The granulites rocks may be grouped in two tectonic associations. The calc-alkaline nature of CAS1 and CAS2 indicate a convergent tectonic setting similar to modern active margins, and the tholeiitic character of B1 group and alkaline of B2 group suggest intracontinental extensional settings.

The relationship between these two contrasting tectonic associations was obliterated by the intense shortening during the Brasiliano orogeny. However, the CAS1 has the most widespread areal distribution (Fig. 2), while the basic B1 and B2 groups concentrate respectively at the base of the upper-

Figure 15 - (a) - N-MORB normalized (Pearce 1983) spidergrams of the B1 group (grey shaded area) compared with typical compositions of Island-arc basalt, E-MORB, Back-arc basalt and Within plate Tholeiitic basalt (data from Wilson 1988, table 6.6, p 176). (b) - N-MORB normalized (Pearce 1983) of the B1 group (grey shaded area) compared with typical compositions of Phanerozoic Continental Intraplate Basalts (Data from Wilson 1988, tables 10.2, 10.3 and 10.4, pp 299-301). (c) - N-MORB normalized (Pearce 1983) spidergrams of the B1 group (grey shaded area) compared with typical compositions of Proterozoic Continental Intraplate Basalts (data from Valeriano 1992-Low TiO_2 fractionated Meso/Neoproterozoic basic rocks from the Nappe Passos, Brasília belt, Brazil; and Condie *et al.* 1987- Proterozoic dyke swarms of Canadian shield), (d) - N-MORB normalized (Pearce 1983) spidergrams of the B2 group (grey shaded area) compared with typical compositions of Ocean Island alkaline basalt and Continental within plate alkaline basalt (Data from Wilson 1988, table 6.6, p 176).

Figura 15 - (a) - Aranhogramas multielementais normalizados por N-MORB (Pearce 1983) das rochas do grupo B1 (área cinza do diagrama), comparadas a composições típicas de basaltos de arco de ilhas, basaltos do tipo E-MORB, basaltos toleíticos intraplaca e basaltos de retro-arco. (dados extraídos da Tabela 6.6 de Wilson, 1988). (b) - Aranhogramas multielementais normalizados por N-MORB (Pearce 1983) das rochas do grupo B1 (área cinza do diagrama), comparadas a composições típicas de basaltos toleíticos continentais fanerozoicos (dados extraídos das tabelas 10.2, 10.3 e 10.4 de Wilson 1988, pp 229-301). (c) - Aranhogramas multielementais normalizados por N-MORB (Pearce 1983) das rochas do grupo B1 (área cinza do diagrama), comparadas a composições típicas de basaltos toleíticos continentais proterozoicos (dados extraídos de: Valeriano 1992- Metabasitos de Baixo TiO_2 , fracionados, Meso/Neoproterozoicos da região da Nappe de Passos, Faixa Brasília; e Condie *et al.* 1987- enxames de diques proterozoicos do escudo canadense). (d) - Aranhogramas multielementais normalizados por N-MORB (Pearce 1983) das rochas do grupo B2 (área cinza do diagrama), comparadas a composições típicas de basaltos alcalinos de ilhas oceânicas e de ambientes intracontinentais. (dados extraídos da Tabela 6.6 de Wilson, 1988).

most thrust sheet and at the intermediate thrusts sheet. This spatial distribution, the relict magmatic textures in CAS1 samples and its field relationship with CAS2, suggest that CAS1 represents the basement to the other calc-alkaline and basic rock assemblages, and probably the oldest segment of continental crust. It is also suggested that B1 (tholeiitic) and B2 (alkaline) sample groups may represent extensional tectonic episodes (continental flood magmatism and dykes) that took place in the older continental crust. All rocks belonging to the different tectonic environments were metamorphosed under granulite facies during the Transamazonian.

Available geochronological data for the JFC in the investigated region are one U/Pb discordia of CAS2 with Paleoproterozoic and Neoproterozoic intercepts (Machado *et al.* 1996) and two Rb/Sr errorchrons (Heilbron 1993) that corroborate the Paleoproterozoic age of the granulite facies metamorphism, overprinted on juvenile protoliths. Only detailed geochronological data associated with isotopic studies could contribute to solve the temporal succession and the sources of the other JFC rocks.

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- The geochemical data of studied area show that the common LILE depletion of other granulite terranes was not detected in the JFC. Except for a few CAS1 samples that have selective Rb removal and consequently higher K/Rb ratios, the other granulite samples have LELE contents similar to the upper crust average (Taylor & McLennan 1985). The Eu/Eu* ratios and the bulk composition of the studied granulites do not corroborate the lower crust residue models proposed previously. If these assumptions are correct, the Juiz de Fora Complex could be regarded as the root of a Paleoproterozoic active margin (Teixeira & Figueiredo 1991), tectonically overthrust during the Brasiliano orogeny.

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