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MAFIC GRANULITES AND AMPHIBOLITES OF THE SÃO JOSÉ DO RIO PARDO – CACONDE HIGH GRADE TERRAIN

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ABSTRACT

Basic rocks, although very abundant, represent bands or lenses within migmatites and gneisses, commonly occurring as boudins within the high grade rocks in the São José do Rio Pardo-Caconde region, states of São Paulo and Minas Gerais. These rocks are represented by amphibolites, salite amphibolites and basic granulites (metagabbronorites) made up, essentially, of plagioclase (An_{40-70}), brown hornblende, clinopyroxenes and orthopyroxenes.

Major and trace elements geochemistry show good correlations between many elements, a tholeiitic character for the granulites and a more calc-alkaline for the amphibolites, although an enrichment in alkalis has been observed for these rocks.

Considering the different concentrations of TiO_2 in these rocks with higher content types (amphibolites) and lower-content ones (granulites), it is possible to propose a derivation from heterogeneous parts of the mantle to explain the origin of these basic rocks.

RESUMO

Rochas básicas, embora muito abundantes, representam bandas ou lentes dentro dos migmatitos e gnaisses, freqüentemente boudinadas, dentro da associação de alto grau que compõe a região de São José do Rio Pardo-Caconde. São anfibolitos, salita anfibolitos e granulitos básicos (metagabronoritos), constituídos essencialmente por plagioclásio (An_{40-70}), hornblenda marron, clinopiroxênio e ortopiroxênio.

Dados referentes a elementos maiores e traço evidenciam boas correlações entre vários elementos, um caráter toleítico para os granulitos e mais cálcio-alcalino para os anfibolitos, embora seja observado um enriquecimento em alcalis para essas rochas.

Considerando que, os anfibolitos e os granulitos podem ser classificados como de alto e baixo Ti respectivamente, é possível admitir para essas rochas uma derivação a partir de porções heterogêneas do manto, descartando-se uma origem comum por processos de diferenciação magmática.

INTRODUCTION

In south Minas Gerais state and in northeast São Paulo state, between the cities of São José do Rio Pardo and Muzambinho occurs a broad and extensive granulite facies belt. Geological work in this area shows that it is composed of high grade rocks such as granulites, banded gneisses of the charnockite series, orthogneisses, migmatites and metasedimentary types like quartzites, quartz-feldspathic, kinzigitic and calc-silicate gneisses (Oliveira, 1973; Oliveira & Alves, 1974; Oliveira et al., 1983; Campos Neto & Figueiredo, 1985; Oliveira et al., 1986; Campos Neto et al., 1988). This granulite belt is included in the Alfenas belt of Almeida et al. (1980) to the north, and to the south in the Guaxupé Massif (Almeida et al., 1976) or in the Varginha Complex (Fonseca et al., 1979; Cavalcante et al., 1979).

Basic granulites and amphibolites are intercalated in all lithologies in the whole area (Oliveira, 1973; Oliveira & Hypolito, 1978; Choudhuri et al., 1989). These basic granulites are the focus of the present study, and their geochemical and petrological data are presented and discussed here.

GEOLOGICAL SETTING

A sketch map of the area is shown in Figure 1 with the lithologies grouped in three major units:

1. Migmatites and orthogneisses are predominant in the southeast part of the area, including many intercalations of mangerite to charnockite gneisses (Campos Neto et al., 1988). Banded, folded, ophthalmic and nebulitic structures are predominant in the migmatites, with tonalitic, dioritic, granulitic and amphibolitic paleosomes (Oliveira, 1973; Oliveira & Alves, 1974; Oliveira et al., 1983; Morales et al., 1988). It is also possible to distinguish more homogeneous areas with hornblende granitoids, syenitic and granodioritic gneisses with augen structures as a consequence of strong deformations.

2. The central region is dominated by

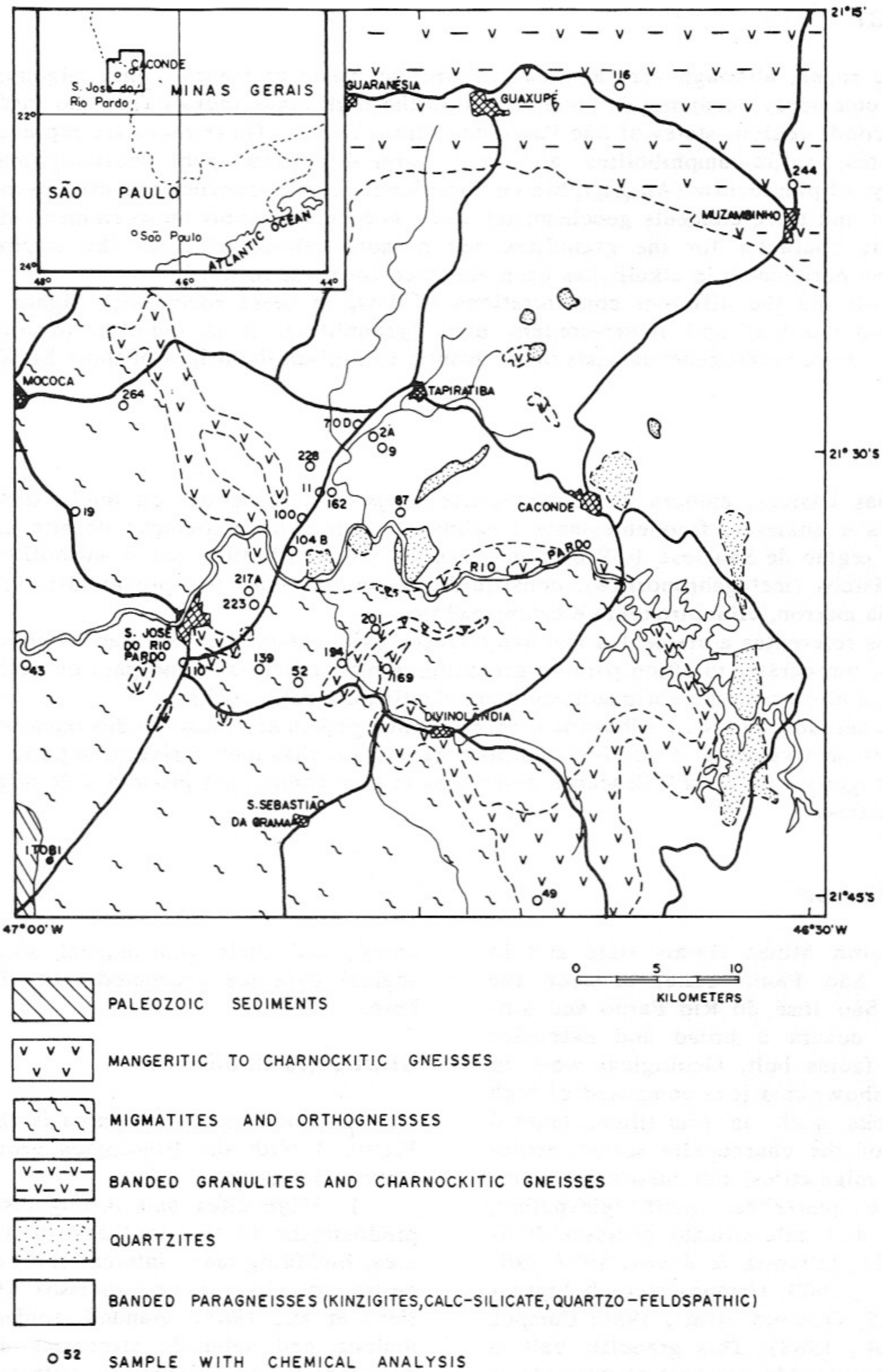

Figure 1 – Schematic geological map of the area.

metasedimentary types, with quartz-feldspathic composition and migmatite features. In pelitic gneisses and calc-silicates, paragenesis such as cordierite - sillimanite - garnet and diopside - scapolite - wollastonite have an important petrological significance, indicating low to medium pressures (6-7 Kb) and temperatures greater than 700°C for their formation (Oliveira & Alves, 1974; Oliveira & Ruberti, 1979). Quartzites and charnockites are also present in this region.

3. To the north, banded granulites and charnockites form a part of the Alfenas Granulite Belt. Their compositions vary from acid to basic. Centimetric charnoenderbitic layers occur with more basic ones, as well as with dioritic to gabbroic compositions (Santos, 1987). In some outcrops, the feldspathic bands are mobilizated and the whole-rock presents a banded migmatite appearence.

A low angle foliation, parallel to banding, is the most important structure in this area.

The amphibolites and basic granulites, although very abundant, represent small bodies which occur as bands or lenses within migmatites and other lithologies. Commonly they represent boundins formed as a consequence of the deformational process that affected the whole area.

PETROGRAPHY OF AMPHIBOLITES AND BASIC GRANULITES

Amphibolites, salite amphibolites and metagabbronorites (basic granulites) represent the chief petrographic types studied. They are essentially made up of plagioclase, brown hornblende, clinopyroxene and orthopyroxene, with biotite and opaque minerals as accessories. In some of them (samples 9 and 70D), olivine, garnet and scapolite occur occasionally.

In these rocks, plagioclase of andesine and labradorite (An_{40}-An_{70}) composition are common. Pale green clinopyroxene (salite-ferrosalite) is always corroded, showing fractures, and is associated with or enclosed by hornblende; orthopyroxenes are represented by hypersthene and ferrohypersthene with pale green to pale pink pleochroism, always corroded and associated with clinopyroxenes or hornblende, and are found only in basic granulites. Hornblende shows dark green to brown pleochroism and commonly crystallizes later, surrounding pyroxenes, with poikiloblastic texture. In general textures are granoblastic to nematoblastic with superimposed cataclasis. As a result plagioclase is saussuritized and pyroxenes are transformed to pale green hornblende.

As pointed out by Choudhuri (1984), hornblende is frequently absent in quartz-feldspar granulites, but in basic granulites, with two pyroxenes and no free quartz, it is stable. In these rocks, the green hornblende is in great part a retrograde phase.

The mineral paragenesis in the whole area reflects the occurrence of various metamorphic events, the main one of high grade, indicated by the association of clino-and orthopyroxene in basic rocks. The presence of brown hornblende associated with the pyroxenes indicates the hornblende subfacies of the granulite facies. Two pyroxene geothermometry shows temperatures close to 800°C for the granulite metamorphism (Oliveira & Hypolito, 1978; Santos, 1987). Part of the amphibolites may be included in the high grade metamorphism.

The amphibolite facies paragenesis results from the migmatization event associated with intense regional shearing favouring the formation of green hornblende and biotite.

MAJOR AND TRACE ELEMENT VARIATION

From a group of 24 samples, 8 are basic granulites (metagabbronorites 217A, 162, 228, 116, 223, 87, 19) and the remaining 16 are amphibolites with some modal diopside. Sample 194 has modal olivine and may be classified as an ultramafic granulite. Sample 9 contains garnet and scapolite. Chemical analysis for these rocks is presented in Table 1. Major and trace element analyses were obtained in the Museè Royal de l'Afrique Centrale, Belgium, by X-ray fluorescence except for Cu, Ni and Co which were analysed by atomic absorption by Puriquima Ltda, São Paulo, Brazil.

The chemical composition of amphibolites and granulites are presumed not to have been affected on a large scale by high grade metamorphism, as has been observed by many authors in other regions (Rivalenti & Rossi, 1975; Kalsbeek, 1970; Glikson, 1972; Correira & Girardi, 1989). In this respect, the relations between Na_2O and K_2O (Miyashiro, 1975) confirm an almost isochemical metamorphism.

The SiO_2 content is characteristic of basic rocks ranging from 39,5 to 52,5. For Al_2O_3 (6,8 to 22,0) and MgO (3,8 to 18,2) the values can be considered normal, except for sample 9 that can be related to calc-silicate types.

Major and trace element variations are shown in Figure 2 and a chemical range with good correlations are registered for CaO, Na_2O, K_2O, P_2O_5, Al_2O_3 and Zr. For

Table 1 – Major and trace element compositions of amphibolites and basic granulite.

	217A	104B	43	162	169	228	2A	110	116	49	244	11
SiO_2	52,57	50,59	48,71	48,65	48,64	47,83	47,73	47,66	47,63	47,17	46,42	46,42
Al_2O_3	17,44	15,80	19,47	6,88	17,13	9,68	13,88	13,53	14,61	17,36	15,47	18,16
Fe_2O_3	4,39	3,34	3,25	3,42	2,61	4,68	4,45	4,05	2,54	3,86	4,60	5,06
FeO	4,30	7,53	7,39	7,93	6,55	5,49	8,62	7,90	7,36	7,18	6,35	1,07
MnO	0,17	0,17	0,18	0,22	0,17	0,18	0,30	0,20	0,16	0,19	0,18	0,17
MgO	4,39	5,08	10,35	13,83	9,78	13,98	6,20	7,56	9,84	3,85	6,87	4,14
CaO	8,18	7,67	12,81	13,20	10,32	13,28	10,29	9,18	11,62	9,41	9,66	7,91
Na_2O	3,35	4,28	1,82	1,75	3,06	1,63	3,41	3,41	1,97	5,02	4,08	4,55
K_2O	2,01	2,29	0,77	0,38	0,50	0,29	1,44	2,00	0,50	1,58	1,53	1,95
TiO_2	0,83	1,58	0,90	0,83	1,03	0,57	1,97	1,34	0,87	2,14	1,64	1,67
P_2O_5	0,37	0,67	0,23	0,13	0,29	0,08	0,64	0,43	0,76	1,40	0,60	0,53
H_2O^+	0,58	1,17	2,98	1,57	1,00	1,49	1,23	1,96	2,66	1,22	2,15	1,16
Total	98,58	100,17	99,86	98,79	101,08	99,18	100,16	99,22	99,92	100,38	99,55	98,79
Mg	0,38	0,46	0,64	0,69	0,66	0,72	0,46	0,53	0,64	0,39	0,53	0,38
Rb	56,6	67,3	24,7	7,8	8,76	15,2	38,6	59,5	13,8	37,8	29,1	85,0
Sr	370	374	355	172	366	96,7	150	171	621	922	1025	338
Y	32,4	40,8	22,3	19,6	23,3	16,0	65,6	94,6	25,0	65,5	26,1	49,5
Zr	174	273	110	59,3	146	45,7	138	303	152	503	255	193
Cu	10	19	70	120	44	81	2	32	30	17	5	26
Ni	37	52	210	330	50	260	66	100	185	15	130	17
Co	46	40	75	79	62	79	47	43	64	40	52	33
Rb/Sr	0,1530	0,1799	0,0696	0,0453	0,0239	0,1572	0,2573	0,3480	0,0222	0,0410	0,0284	0,2515
K/Rb	296	283	260	405	475	159	311	280	302	348	438	188

(Cont. Table 1)

	52	70D	223	87	194	139	264	19	201	9	100
SiO_2	46,12	46,06	44,98	44,81	44,09	43,68	43,65	41,76	41,47	39,58	39,53
Al_2O_3	16,39	13,66	13,06	12,83	8,07	15,92	15,58	10,80	11,83	22,00	15,02
Fe_2O_3	4,13	1,75	5,72	10,43	9,12	7,69	5,06	6,65	7,33	5,17	10,20
FeO	9,11	11,75	10,78	6,15	6,47	6,82	8,94	10,75	10,98	2,01	6,42
MnO	0,18	0,27	0,24	0,23	0,23	0,19	0,21	0,17	0,23	0,19	0,26
MgO	5,83	6,86	6,82	5,88	18,23	5,84	6,35	10,56	7,96	6,22	8,03
CaO	9,17	11,63	10,46	11,71	8,03	9,71	10,46	11,70	10,75	17,97	11,22
Na_2O	3,88	3,07	2,87	3,27	1,98	3,35	3,77	1,99	2,87	0,75	2,63
K_2O	1,12	0,86	1,04	0,20	0,80	1,36	1,32	0,65	1,12	2,54	0,95
TiO_2	2,03	1,95	1,95	2,95	1,00	2,35	1,79	2,21	2,59	1,55	1,90
P_2O_5	0,52	0,34	0,39	0,53	0,36	0,92	0,84	0,23	0,29	0,89	0,95
H_2O^+	1,56	2,05	1,20	0,70	1,51	1,39	1,61	2,10	2,20	0,94	1,81
Total	100,04	100,14	99,51	99,69	99,89	99,22	99,58	99,57	99,62	99,81	98,91
Mg	0,44	0,47	0,43	0,40	0,69	0,43	0,45	0,53	0,44	0,62	0,47
Rb	33,1	22,0	17,4	8,82	26,8	40,1	22,4	24,4	17,6	747	19,5
Sr	699	282	156	244	260	607	707	622	529	801	499
Y	41,5	126	58,6	58,6	20,8	36,6	74,7	184	17,7	36	67,3
Zr	1291	126	219	197	107	201	209	170	164	254	148
Cu	21	17	69	92	50	50	37	120	62	2	50
Ni	30	79	190	78	370	56	44	260	190	35	87
Co	48	49	100	67	120	51	54	110	97	17	60
Rb/Sr	0,0474	0,0780	0,1115	0,0361	0,1031	0,0661	0,0317	0,0392	0,0333	0,9326	0,0391
K/Rb	273	312	498	189	249	282	491	222	530	28	410

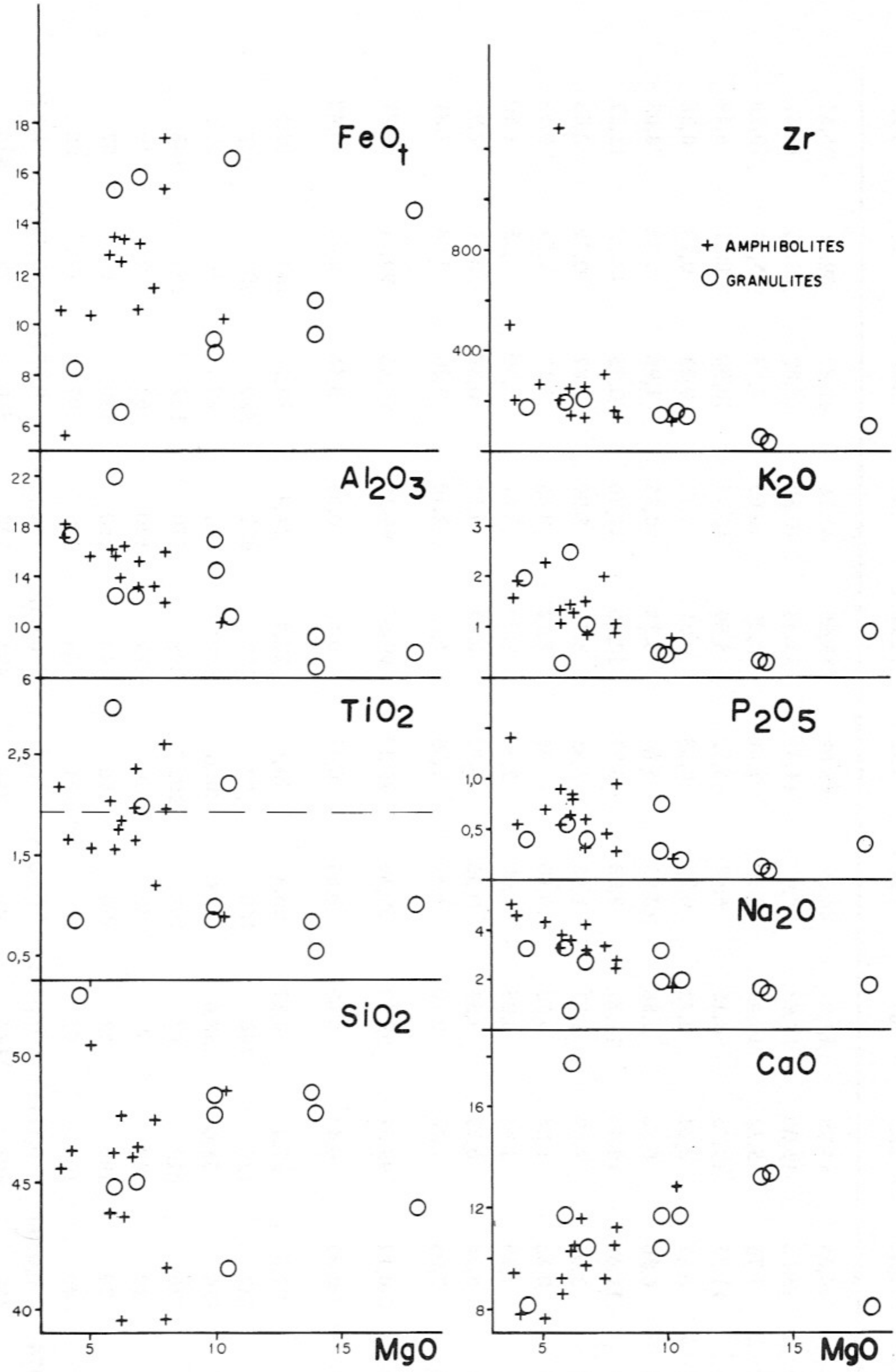

Figure 2 – Variation diagram of FeO, Al_2O_3, TiO_2, SiO_2, CaO, Na_2O, K_2O, P_2O_5 and Zr vs. MgO content.

some elements such as FeO and TiO_2, the granulites have different concentrations in relation to amphibolites. Some of the samples have a high TiO_2 content, and it is possible to subdivide the whole suite into two groups: one higher in TiO_2 and the other lower in TiO_2.

A tholeiitic character for granulites

and a calc-alkaline one for amphibolites is clearly shown on the AFM diagram (Fig. 3). The calc-alkaline trend for the charnockitic rock series of São José do Rio Pardo has been registered previously by Oliveira (1973) and Oliveira & Morales (1988). An enrichment in alkalis ($Na_2O + K_2O$) is also clear in Figure 4, with a more alkaline trend for amphibolite, as shown by Santos (1987) for similar rocks in the Guaranésia region, north of the studied area, probably due to migmatization effects (Choudhuti et al., 1989).

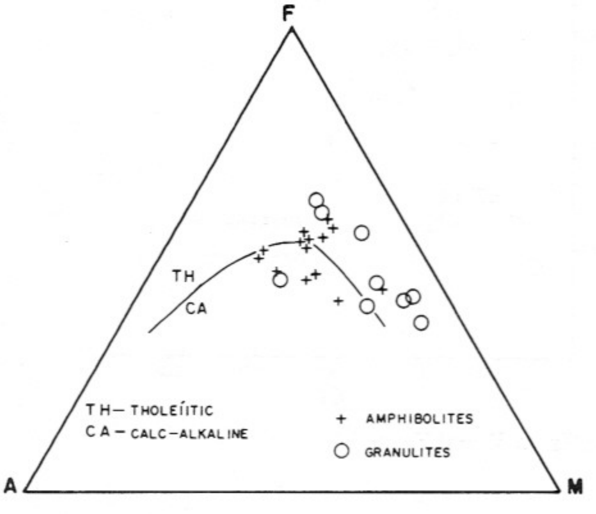

Figure 3 – AFM diagram. CA-TH: boundary between tholeiitic and calc-alkaline series (Irvine & Baragar, 1971).

Y and Ti show positive correlation when compared with Zr, whereas Ni and Co are depleted (Fig. 5). Some granulites have a distinct behaviour, particularly with respect to Ti, showing low concentration of this element.

Plots of Ni and TiO_2 versus mg are shown in Figure 6 (Gill, 1979). High concentrations of Ni are recorded for Archean tholeiites when compared with modern ones (MORB, IAT and MB). The studied rocks show good correlations chiefly for Mg and Ni as observed by Santos (1987) for the Guaranésia region.

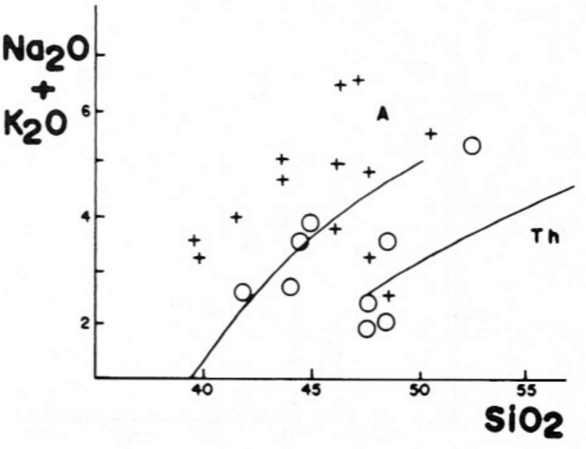

Figure 4 – (K_2O + Na_2O) versus SiO_2 diagram. The lines separating alkali (A) high-alumina (HAl) and tholeiitic basalts (Th) are from Kuno (1966) and Irvine & Baragar (1971).

CONCLUSIONS

Geological and geochemical data indicate that the basic granulites and amphibolites have a complex geological evolution. Basic bodies of variable dimensions, most of them of magmatic derivation, now disrupted by ductile shearing processes, and associated with gneisses and granulites may represent sill-like intrusions (Choudhuri et al., 1989) or extrusions related to volcanic activity.

The evidences obtained from the geochemical diagrams show a derivation from a tholeiitic or calc-alkaline series, the latter corresponding now to charnockitic or mangeritic suites, and associated granitoids (Oliveira, 1973; Oliveira & Morales, 1988; Campos Neto et al., 1988).

Choudhuri et al. (1989) studying differentiated mafic bodies from the high-grade terrain of the Guaxupé massif concluded that they belong to a tholeiitic series with slight alkali enrichment in some samples and that no significant contamination by crustal materials took place in these rocks.

The existence of low and high TiO_2 groups (granulites and amphibolites respectively) suggests that the entire basic rock framework could not be derived from the same magma by differentiation processes and that their origin may be related to the occurrence of heterogeneous material in the mantle (Correia & Girardi, 1989; Walker et al., 1990).

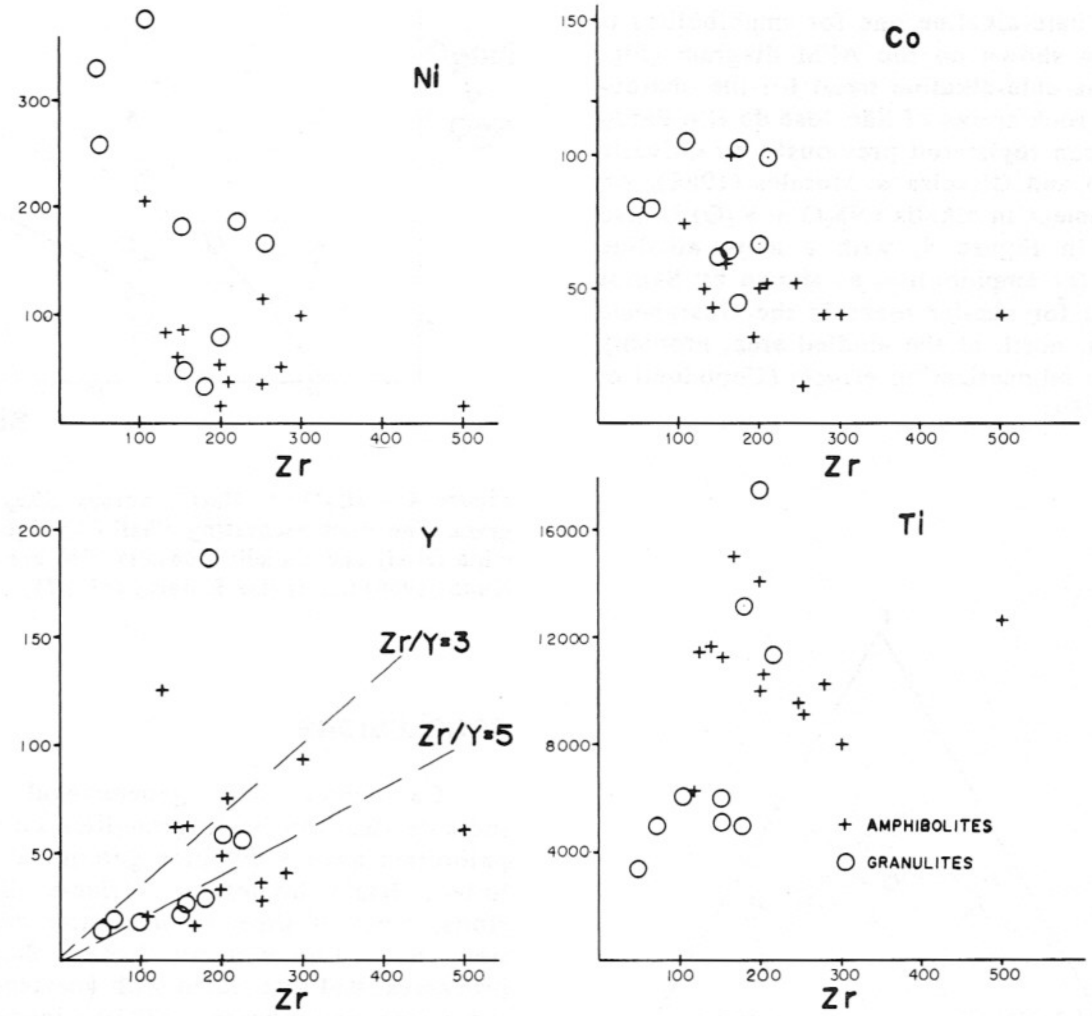

Figure 5 – Variations diagrams of Zr vs Ni; Zr vs Co; Zr vs Y and Zr vs Ti.

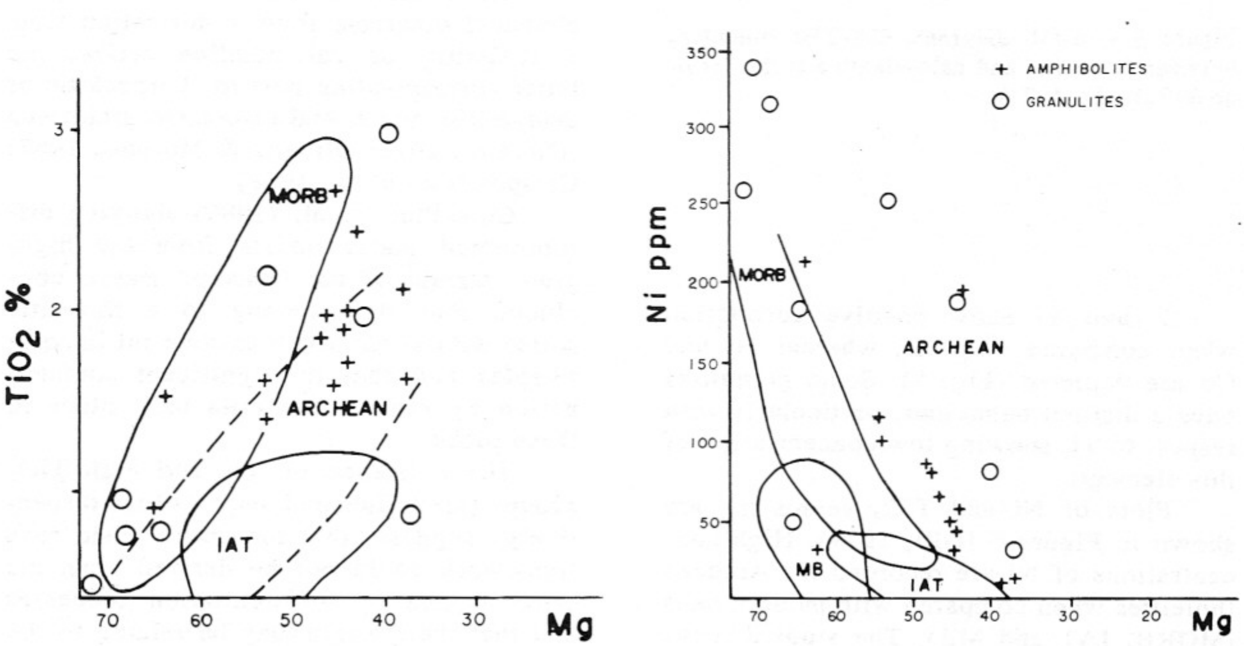

Figure 6 – TiO_2-mg and Ni-mg covariation diagram comparing amphibolites and granulites of São José do Rio Pardo with modern tholeiites from ocean floor (MORB), island arc (IAT) and marginal basins (MB) and with Archean analogues (fields and Mg from Gill, 1979).

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