GEOCHEMICAL SIGNATURE OF THE BRASILIANO–AGE PLUTONISM IN THE SERIDÓ BELT, NORTHEASTERN BORBOREMA PROVINCE (NE BRAZIL)

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ABSTRACT The Seridó Belt (Borborema Province, NE Brazil) displays a strong imprint of the late Neoproterozoic Brasiliano orogenic cycle. The most important megascopic structures in the Seridó Belt are strike-slip shear zones, coeval with the emplacement of several granitoid bodies. The paper is based on 217 chemical analyses of the granitoid plutons grouped into five different geochemical suites (***Shos*** - *Shoshonitic*, ***PKCAlk*** - *Porphyritic K-Calc-Alkaline*, ***EqKCAlk*** - *Equigranular K-Calc-Alkaline*, ***Alk*** - *Alkaline* and ***ChAlk*** - *Charnockitic Alkaline*). They are distinguished by petrographic and textural features, as well as Harker's and geochemical discriminant diagrams. The ***Shos*** is easily distinguished from the others by its low silica content, while the ***Alk*** and ***ChAlk*** suites have high alkali contents. The ***PKCAlk*** and ***EqKCAlk*** show similar geochemical behaviour; but they can be separated mainly by petrographic and textural aspects. Field relationships and geochemical affinities suggested that the ***Shos***, ***PKCAlk***, ***EqKCAlk*** and ***Alk*** are approximately coeval, syntectonic plutons, whereas the ***ChAlk*** is interpreted as late- to post-tectonic as regards to the Brasiliano orogeny.

Keywords: Seridó Belt, Brasiliano orogeny, plutonism, geochemistry, discriminant diagrams

INTRODUCTION

One of the most characteristic features of the Seridó Belt is the huge plutonic activity at the end of the Brasiliano Cycle (550 ± 50 Ma). This plutonism is represented by a large number of batholiths, stocks and dikes, widely distributed in the Seridó Belt (Fig. 1) and displaying different petrographic and geochemical characteristics.

Different classification proposals were elaborated at a regional basis, encompassing all the Borborema Province. The classical paper of Almeida *et al.* (1967) subdivided the granitoid rocks, with respect to the Brasiliano orogeny, into four groups: the syntectonic Itaporanga and Conceição types, and the late-tectonic Catingueira and Itapetim types. Geochemical classifications of Brasiliano granitoids were put forward by Sial (1986) and Ferreira *et al.* (1998), among others, who emphasized the magmatic affinities of these rocks.

In the Seridó Belt, Jardim de Sá *et al.* (1981) called attention to the emplacement of the granitoid rocks related to different orogenic episodes, and named the Brasiliano plutons as the *G_3 granitoids* (porphyritic or equigranular, besides late leucogranites and basic-to-intermediate rocks). Jardim de Sá (1994) characterized the "basic-to-intermediate", "porphyritic" and "leucogranite" suites, besides syn- and post-tectonic alkaline suites, later on described by Galindo (1993), Hollanda (1998), Nascimento (1998), Jardim de Sá *et al.* (1999) and Nascimento (2000).

The present paper aims to synthesize the chemical data presently available in the region (217 analyses) and to propose a uniform systematic nomenclature for the Brasiliano-age plutonism in the Seridó Belt.

GEOCHEMICAL CHARACTERISTICS OF THE PLUTONIC SUITES

The database used for the classification proposal was selected from a number of the chemical analyses available in the literature (all references used are listed in Table 1), dealing with the several Brasiliano-age plutons. The data were treated, excluding those with anomalous values. Samples of doubtful provenance were not considered.

This classification was based mainly upon the chemical characteristics of each sample group, as well as on their petrographic aspects and modal compositions. The nomenclature of each group or suite reflects to its magmatic affinity, identified by discriminant diagrams. In this work, it was possible to characterize five plutonic suites in the Seridó Belt, named as follows: Shoshonitic (*Shos*), Porphyritic K-Calc-Alkaline (*PKCAlk*); Equigranular K-Calc-Alkaline (*EqKCAlk*); Alkaline (*Alk*) and Charnockitic Alkaline (*ChAlk*). All these suites are represented in figure 1.

The Shoshonitic Suite (Shos)

It occurs as isolated plutons (e.g. São João do Sabugi and Quixaba) or closely associated to the *PKCAlk Suite* (e.g. São José de Espinharas, Totoró and Cardoso). It comprises rocks of varied composition, ranging from gabbro/diorite to quartz monzonite, with equigranular or inequigranular fine- to medium-grained texture (coarser in the gabbroic terms, sometimes with plagioclase phenocrysts). The latter types also exhibit augite, diopside and/or hypersthene phenocrystals, which may be transformed to amphibole. In the most differentiated types (diorites and quartz monzonites), hastingsitic to Fe-edenitic hornblende is the dominant mafic phase, besides biotite. The commonest accessory minerals are sphene, opaque minerals (magnetite and/or ilmenite), zircon and apatite.

The SiO_2 contents in the *Shos Suite* vary between 48 and 60%, corresponding to the least differentiated plutonic rocks studied. The K_2O/Na_2O ratio ranges from 0,3 to 1,6 (Table 2). Harker's diagrams (SiO_2 as the differentiation index), show negative correlation for Fe_2O_{3t} and MgO, and positive for K_2O (Fig. 2). Rb, Ba and Zr have typically incompatible behavior, whereas Sr seems to be a compatible element for SiO_2 values greater than 55 % wt (Fig. 2). The REE are weakly to moderately fractionated (La_N/Yb_N=11-70), with positive or negative Eu anomalies (Table 2).

The Porphyritic K-Calc-Alkaline Suite (PKCAlk)

It is widely distributed in the Seridó Belt, being represented by isolated batholiths or plutons associated to the other suites, especially the *Shos*. The *PKCAlk Suite* comprises porphyritic coarse-grained rocks with high proportions of K-feldspar phenocrystals. It is the dominant facies in the majority of the granitoid massifs, like the ones of Acari, Monte das Gameleiras, São José de Espinharas, Serra do Lima-Caraúbas, Barcelona and Totoró (Fig. 1). Medium-grained varieties, in which the K-feldspar phenocrystals are smaller than 2 cm in length, may also occur. The *PKCAlk* plutons have mainly a monzogranitic composition, although granodioritic and quartz monzonitic varieties may be found. The mafic phases are biotite, hastingsitic to Fe-edenitic hornblende, while sphene, epidote, allanite, zircon, apatite and magnetite are the main accessory minerals.

The *PKCAlk Suite* exhibits alkali enrichment (K_2O+Na_2O³7%), and has the greatest K_2O/Na_2O (Table 2). In Harker's diagrams, Fe_2O_{3t} and MgO are negatively correlated against SiO_2 (Fig. 2). Both Sr and Ba have compatible behavior, whereas Rb appears to be an incompatible element (Fig. 2). Concerning the REE, they are weakly to moderately fractionated, with $(La/Yb)_N$ ratios between 20 and 80, and always show moderately to strongly negative Eu anomalies (Table 2).

The Equigranular K-Calc-Alkaline Suite (EqKCAlk)

Rocks of the *EqKCAlk Suite* occur as sheets, dikes and sills, isolated bodies (e.g. Taipu, Dona Inês and Picuí plutons - Fig. 1) or associated to the *PKCAlk Suite* (e.g. Acari and São José de Espinharas plutons). This suite is composed principally by fine- to medium-grained equigranular monzogranites. The main accessory mineral is biotite (± amphibole), besides subordinated amounts of sphene, epidote, opaque minerals, apatite, zircon, allanite and tourmaline. Some facies of the Picuí (Silva 1993) and Dona Inês plutons (McMurry *et al.* 1987) contain garnet.

The *EqKCAlk Suite* shows narrow SiO_2 variation (68-76%) and high K_2O/Na_2O ratio (1,1-2,3). Harker's diagrams (Fig. 2) present negative correlation for Fe_2O_{3t}, MgO and Na_2O. Sr, Ba and Zr show compatible behavior, and Rb is an incompatible element (Fig. 2).

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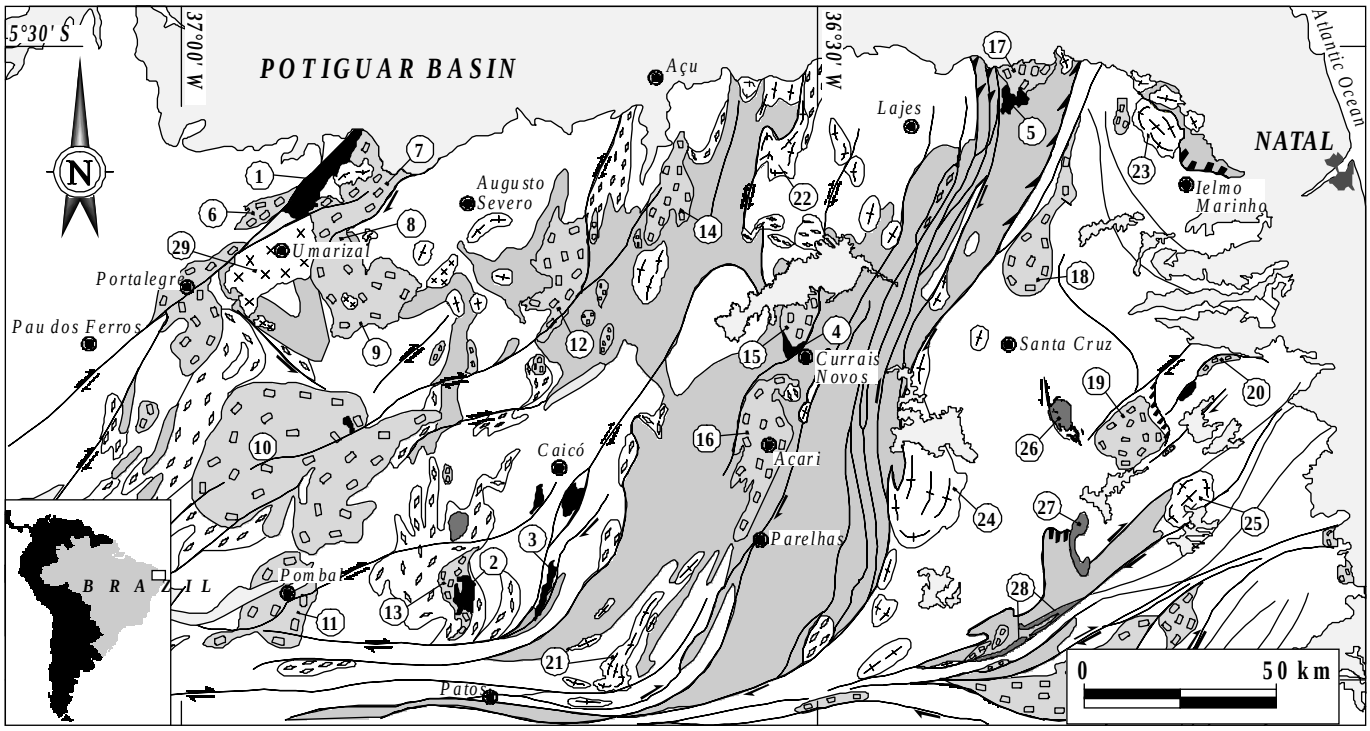

BRASILIANO-AGE PLUTONS OF THE SERIDÓ BELT

Shoshonitic Suite		*Porphyritic K-Calc-Alkaline Suite*								*Equigranular K-Calc-Alkaline Suite*	
1	Quixaba	6	Prado	11	Pombal	16	Acari			21	Santa Luzia
2	São José de Espinharas	7	Caraúbas	12	Serra João do Vale	17	Cardoso			22	Angicos
3	São João do Sabugi	8	Tourão	13	São José de Espinharas	18	Barcelona			23	Taipu
4	Totoró	9	Serra do Lima	14	São Rafael	19	Monte das Gameleiras			24	Picuí
5	Cardoso	10	Catolé do Rocha	15	Totoró	20	Serrinha			25	Dona Inês

Alkaline Suite		*Charnockitic Alkaline Suite*	
26	Japi	29	Umarizal
27	Caxexa		
28	Serra do Algodão/Serra do Boqueirão		

a c e g i k m
b d f h j l n

Figure 1 - Geological map of the Seridó Belt, emphasizing the Brasiliano magmatic suites (modified after Jardim de Sá 1994). ***a*** *- Meso to Cenozoic covers;* ***b*** *- Brasiliano alkaline plutons;* ***c*** *- Brasiliano charnockitic alkaline plutons;* ***d*** *- Brasiliano equigranular K-calc-alkaline plutons;* ***e*** *- Brasiliano porphyritic K-calc-alkaline plutons;* ***f*** *- Brasiliano shoshonitic plutons;* ***g*** *- Proterozoic metasupracrustals;* ***h*** *- Paleoproterozoic granitoid plutons;* ***i*** *- Archaean to Paleoproterozoic gneissic-migmatitic basement;* ***j*** *- Brasiliano transcurrent shear zones;* ***k*** *- Brasiliano contractional-transpressive shear zones;* ***l*** *- Brasiliano extensional shear zones;* ***m*** *- Town;* ***n*** *- capital city of state.*

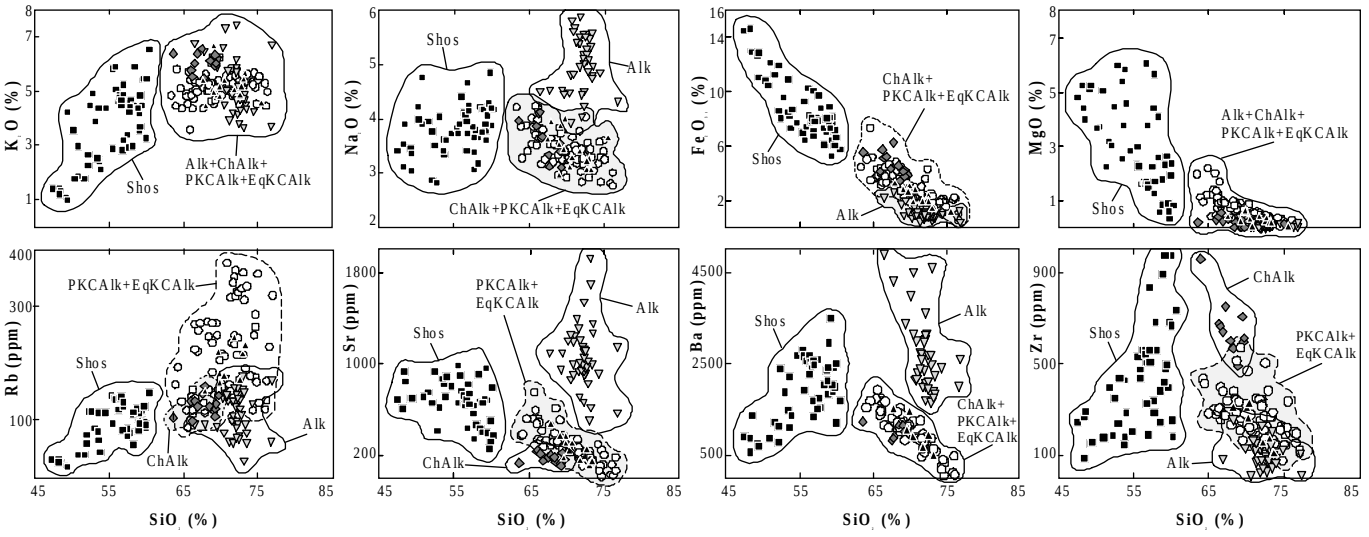

Figure 2 - Harker's diagrams for the Brasiliano-age magmatic suites in the Seridó Belt, using SiO_2 as the differentiation index. Legend: ■ Shos = Shoshonitic, ○ PKCAlk = Porphyritic K-Calc-Alkaline, ▲ EqKCAlk = Equigranular K-Calc-Alkaline, ▼ Alk = Alkaline, ◆ ChAlk = Charnockitic Alkaline.

Table 1 - Bibliographical sources used to characterize the Brasiliano magmatic suites in the Seridó Belt, with a total of 217 chemical analyses (amounts between parentheses).

SUITES (NUMBER OF ANALYSES)	STUDIED PLUTONS	SOURCE
Shoshonitic (57)	São João do Sabugi; Totoró; Acari;	Jardim de Sá (1994), Galindo (1993).
Porphyritic K-Calc-Alkaline (87)	Acari; Totoró; Barcelona; Monte das Gameleiras; Patu-Caraúbas.	Galindo (1982, 1993), Jardim de Sá (1994).
Equigranular K-Calc-Alkaline (17)	Dona Inês; Picuí; Acari; Monte das Gameleiras.	McMurry *et al*. (1987), Silva (1993), Galindo (1982), Jardim de Sá (1994).
Alkaline (45)	Caxexa; Japi; Serra do Algodão; Serra do Boqueirão.	R.S.C. Nascimento (1998), Hollanda (1998), M.A.L. Nascimento (2000).
Charnockitic Alkaline (11)	Umarizal.	Galindo (1993).

Table 2 - Comparative chemical parameters of the Brasiliano magmatic suites in the Seridó Belt. Opx = Orthopyroxene; Cpx = Clinopyroxene; Amph = Amphibole; Bio = Biotite; Garn = Garnet; Sph = Sphene; Fay = Fayalite. Eu/Eu = europium anomaly = $Eu_N/[(Sm_N + Gd_N)/2]$. REE normalized according to the chondritic values of Evensen et al. (1978).*

Suites	Shoshonitic (Shos)	Porphyritic K-Calk-Alkaline (PKCAlk)	Equigranular K-Calk-Alkaline (EqKCAlk)	Alkaline (Alk)	Charnockitic Alkaline (ChAlk)
SiO_2	47,5 - 60,4	61,8 - 76,6	67,7 - 75,5	66,6 - 76,9	63,6 - 69,4
K_2O/Na_2O	0,30 - 1,57	0,85 - 2,14	1,13 - 2,25	0,69 - 1,50	1,36 - 1,96
K_2O+Na_2O	4,35 - 8,98	7,24 - 9,49	8,11 - 9,66	8,03 - 11,23	8,62 - 10,36
Rb/Sr	0,03 - 0,40	0,12 - 2,40	0,32 - 1,81	0,01 - 0,30	0,41 - 1,13
Mafic phases	Opx, Cpx, Amph, Bio	Bio, Amph, Sph	Bio, Garn, Amph	Cpx, Garn, Sph, Amph	Fay, Opx, Cpx Amph, Bio
A/CNK	0,55 - 1,04	0,83 - 1,10	0,95 - 1,12	0,86 - 1,09	0,88 - 1,02
A/NK	1,18 - 2,52	1,15 - 1,51	1,19 - 1,41	0,89 - 1,19	1,13 - 1,27
$(La/Yb)_N$	11 - 70	20 - 80	15 - 135	4 - 17	12 - 62
Eu/Eu*	0,64 - 1,20	0,33 - 0,77	0,37 - 0,72	1,46 - 2,91	0,52 - 1,21
Zr (ppm)	155 - 1000	143 - 397	109 - 330	11 - 230	337 - 962

Moderately to strongly negative Eu anomalies (similar to the ones of *PKCAlk Suite*) and largest range on the $(La/Yb)_N$ ratios (15-135) are remarkable features (Table 2). It is difficult to distinguish it from *PKCAlk Suite*, although the last one has some samples richer in MgO, Rb, Sr and Zr.

The Alkaline Suite (Alk) This suite was recognized in the São José de Campestre Massif, the eastern domain of the Seridó Belt, comprising the Caxexa, Japi, Serra do Algodão and Serra do Boqueirão plutons (Fig. 1). The *Alk Suite* is composed by equigranular, fine-grained alkali-feldspar granites, with subordinate quartz-alkali-feldspar syenite. Aegirine-augite and hedenbergite are the main mafic minerals, although andradite-rich garnet may be observed in the Caxexa, Serra do Algodão and Serra do Boqueirão plutons. The plagioclase is pure albite (An_{0-5}) or slightly enriched in Ca (An_{5-9}) in the garnet-bearing rocks. The accessory minerals are sphene, apatite, zircon, allanite and magnetite.

The *Alk Suite* shows strong enrichment in alkalis, the greatest Na_2O, Sr and Ba contents and the lowest MgO (<0,5%) and Rb/Sr ratios (Table 2; Fig. 2). Figure 2 demonstrates that Sr and Ba are the most compatible elements. These rocks exhibit the least fractionated REE patterns, with $(La/Yb)_N$ ratios between 4 and 17, and a strongly positive Eu anomaly (Table 2).

The Charnockitic Alkaline Suite (ChAlk) Rocks with alkaline affinity also occur in the extreme NW corner of the Seridó Belt, being represented by the Umarizal Pluton, which defines the *ChAlk Suite*. They are composed of medium-grained to inequigranular rocks, with quartz mangeritic to charnockitic composition. Their mafic assemblage may include fayalite (Fa_{98}-Fo_2) or Fe-hypersthene, hedenbergite, Fe-edenitic hornblende and biotite, besides subordinated zircon, apatite, allanite, magnetite and ilmenite.

The *ChAlk Suite* shows high K_2O/Na_2O and Rb/Sr ratios and Zr contents (Table 2). Na_2O, Fe_2O_{3t}, MgO, Ba, Zr and Sr are negatively correlated against SiO_2 (Fig. 2). The REE are fractionated in the same range as found in the *PKCAlk* and *EqKCAlk* suites, but the *ChAlk* is distinguished for having either negative or positive Eu anomalies (Table 2).

GEOCHEMICAL AFFINITIES OF THE PLUTONIC SUITES

The plutonic suites were plotted in some discriminant diagrams for distinguishing their major geochemical affinities (Fig. 3). With respect to the Shand's index, the *Shos Suite* is metaluminous, and the others ones are meta to peraluminous (Fig. 3a), all of them with A/CNK ratio less than 1.2 (Table 2). The suites are transitional between the sub-alkaline and alkaline series, except for the one (*Alk*) which clearly presents an alkaline affinity (Figs. 3b, c, d). The *ChAlk Suite* shows geochemical characteristics transitional between the *Alk* and *PKCAlk* ones, approximately following the monzonitic differentiation trend (Figs. 3b, c).

DISCUSSION AND CONCLUDING REMARKS

The chemical and petrographic comparisons of the Brasiliano-age plutonic rocks allowed the individualization of five main suites: *Shoshonitic*, *Porphyritic K-Calc-Alkaline*, *Equigranular K-Calc-Alkaline*, *Alkaline* and *Charnockitic Alkaline*. *Shos* and *Alk* suites are easily separated from the others. The *ChAlk Suite* can be distinguished from the others in some diagrams. The major difficulty stands in the distinction between *PKCAlk* and *EqKCAlk* suites, once they are chemically very similar. However, petrographic and field aspects should be used to distinguish themselves.

A number of studies in different areas point to a complex geochemical and relative chronology of the Brasiliano-age magmatic suites in the Seridó Belt. Even though representing different parental magmas and sources, frequent magma mingling and mixing features are displayed between the *Shos* and *PKCAlk* suites, which are broadly contemporaneous across the region. The *Alk Suite* displays magmatic and tectonic fabrics of syntectonic intrusions, whereas the *ChAlk Suite* clearly crosscuts the Brasiliano-age regional structures and does not reveal any evidence of ductile deformation, which suggest its late- to post-tectonic emplacement.

According to Jardim de Sá (1994), the outstanding structural control of the plutons by the Brasiliano shear zone network suggests that these structures were deeply rooted, tapping different sources at mantle and lower to middle crustal depths. The sub-alkaline affinity commonly displayed by these igneous suites may be ultimately related to an anomalous and old, enriched lithospheric mantle source directly involved in the petrogenesis of the *Shos* and the alkaline suites. This mantle signature was transferred to the lower crust probably during the Paleoproterozoic tectonomagmatic evolution, and thus explains the sub-alkaline affinity of the crustal-derived Brasiliano granitoids like *PKCAlk* and *EqKCAlk*.

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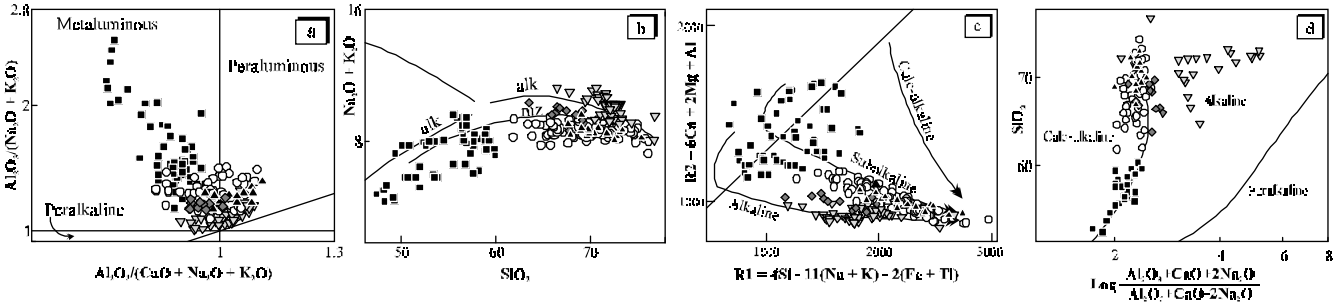

Figure 3 - Geochemical diagrams for the Brasiliano-age magmatic suites in the Seridó Belt. (a) Shand's index (Maniar and Piccoli 1989). (b) Total alkalis vs. SiO_2 with the monzonitic (mz) and alkaline (alk) trends represented (Lameyre 1987). (c) R1-R2 cationic plot (De La Roche et al. 1980). (d) Alkalinity index (Wright 1969). Symbols as in figure 2.

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