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Chemical character of the Ngovayang gneisses in the northwestern border of the Congo craton (south Cameroon): sources and geotectonic framework

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ABSTRACT: This article examines the results of chemical data of the granitoids of the Ngovayang massif at the Northwestern border of the Congo craton in South Cameroon. The aim is to identify the sources and geotectonic framework of emplacement of these formations. It is a contribution to the understanding of the geodynamic context of the Ngovayang massif in the Nyong unit. 24 samples were analyzed by XRF and ICP/MS and are constituted of orthogneiss, charnockitic gneiss, migmatites and metagranites. This study brings out the progressive variation of the nature of the gneissic basement of this massif. Orthogneisses are the principal rocks and are characterized by an enrichment in Na as opposed to an impoverishment in K. This confirms their enrichment in plagioclase and their impoverishment in alkaline feldspar, K/Na ratios < 0.5. Trace element contents are also characteristics, marked by an enrichment in light rare earths (La_{avg}=10.48ppm) and impoverishment in heavy rare earths (Yb_{avg}=0.63ppm). Their spectra are much fractionated ($(La/Yb)_N$=15.86) without any significant anomaly in Eu but a negative anomaly in Ti and Nb. These results confirm its belonging to granitoids of the TTG type of trondhjemitic affinity. The migmatites have a granodioritic composition and are calco-alkaline. They have low Y content and are comparable with the CA2 type of pluton. They originate from the melting of a source containing garnet in melting residues, similar to those generating TTGs. The migmatitic gneisses seem to be the product of sediments. Charnockitic gneisses have two different trends; the firsts are of granodioritic composition and the procedure of their emplacement is that of differentiation similar to that of TTGs. The seconds have a tonalitic composition and formed by the partial melting of a source containing no garnet and eventually no hornblende. No matter the domain, the formations of the sector of study present in a variable manner, an impoverishment in LILE (Rb, Th and sometimes K). These results show that the metamorphites of the Ngovayang massif are the products of archaean granitoids deformed during the collision of the Congo and Sao Francisco cratonic blocks during the Eburnean orogeny.

KEYWORDS: Granitoids, Ngovayang massif, TTG, Congo craton, Geotectonic framework.

1 INTRODUCTION

In Cameroon, the study of the archaean and paleoproterozoic formations carries the mark of several authors. These form a suite in the Ntem complex, whose emplacement would be between 3300 and 2700My (U/Pb on Zircon, [1], [2], [3], [4], [5], [6], [7]). The Sangmelima granodiorite displays a calco-alkaline character meanwhile the Ebolowa TTGs show a trondjemitic character. Geochemical studies of the amphibole-pyroxene bearing gneisses of Meiganga in North Central Cameroon (central part of the Panafrican chain of Cameroon) show that they also have an archaean heritage. Ages determined by the $^{207}Pb/^{206}Pb$ evaporation method on monozircon, are late-archaean (2.6Gy) to paleoproterozoic (1.7Gy) (Ganwa et al., 2008).

In South-Western Cameroon and more precisely in the Nyong complex, several massifs (Songbadjeck, Ngovayang, Mont des Elephants, Rocher du Loup) of more or less imposing heights, outcrop with almost similar characteristics in the morphologic and tectonic plans ([8], [9], [10], [11], [7], [12], [13]). The in-depth geologic study of these massifs would be the key to the elaboration of a geodynamic model of this complex. The Ngovayang massif has been the object of our study. It is located at the borders of Bipindi, Eseka and Lolodorf between 3°10'N and 3°22'N latitude and 10°30'E and 10°40'E of longitude (Fig. 1b). The geologic studies carried out in the locality however remains mapped at the regional scale, assimilating the Ngovayang massif to a fixed point. These formations are regrouped in the paleoproterozoic assemblage (syntectonic to late granitoids) of the Nyong complex ([14], [15], [3], [16], [17], [12], [7]). The first observations, petrographic and geochemical data at the local scale were by [18] and [8]. We made a fresh sampling of the rocks of this massif, focusing on the metamorphosed gneisses. The questions asked were that of the chemical composition of these granitoids, their source and the tectonic framework of their emplacement.

2 GEOLOGICAL SETTING

The explored domain (Fig. 1b), belongs to the substratum of the Nyong basin in the North-western border of the Congo craton in Cameroon (Fig. 1a). This border consists from East to West, of the Ntem and Nyong complexes [19]. The understanding of its historical geodynamics has been subject to several researches. The first authors named it the Ntem complex, sub-divided into three units: the Ntem unit, Lower Nyong series, Ayina unit ([20], [3], [5], [6], [17]). Recent research shows its transformation into two complexes: the Ntem and Nyong complexes ([12], [7], [10], [21], [8]).

The Ntem complex (>2500 My) consists of three principal formations: an intrusive plutonic complex formed of charnockitic rocks, in which we find charnockitic granitoids of TTG composition, non-charnockitic granitoids and syenites; the banded series formed by an assemblage of charnockitic gneisses; ferriferous furrows forming a greenstone belt (basic rocks and ferriferous quartzites). It was affected by the Liberian orogeny ([3], [16], [5], [6], [12], [9], [8]).

The Nyong complex occupies the western border of the Nyong complex remobilized during the Eburnean/transamazonian orogeny (2400-1800 My) associated to the collision between the Congo and Sao Francisco cratons ([14], [16], [22]). It is constituted of TTG, anorthosites, charnockites, gniesses, migmatites, eclogites, metagabbros, quartzites and Banded Iron Formation [20].

On the structural plan, it is marked by a D_2 deformation phase, which resumes the ancient EW Liberian D_1 structures [20], a generalized NE-SW foliation, sub-vertical sinestral shearings and a tangential tectonics with south-east direction, responsible for the overlapping of the Nyong complex on the Ntem ([14], [16], [12], [8]). It was subject to the post-eburnean/transamazonian fracturation reactivated during the panafrican orogeny [16].

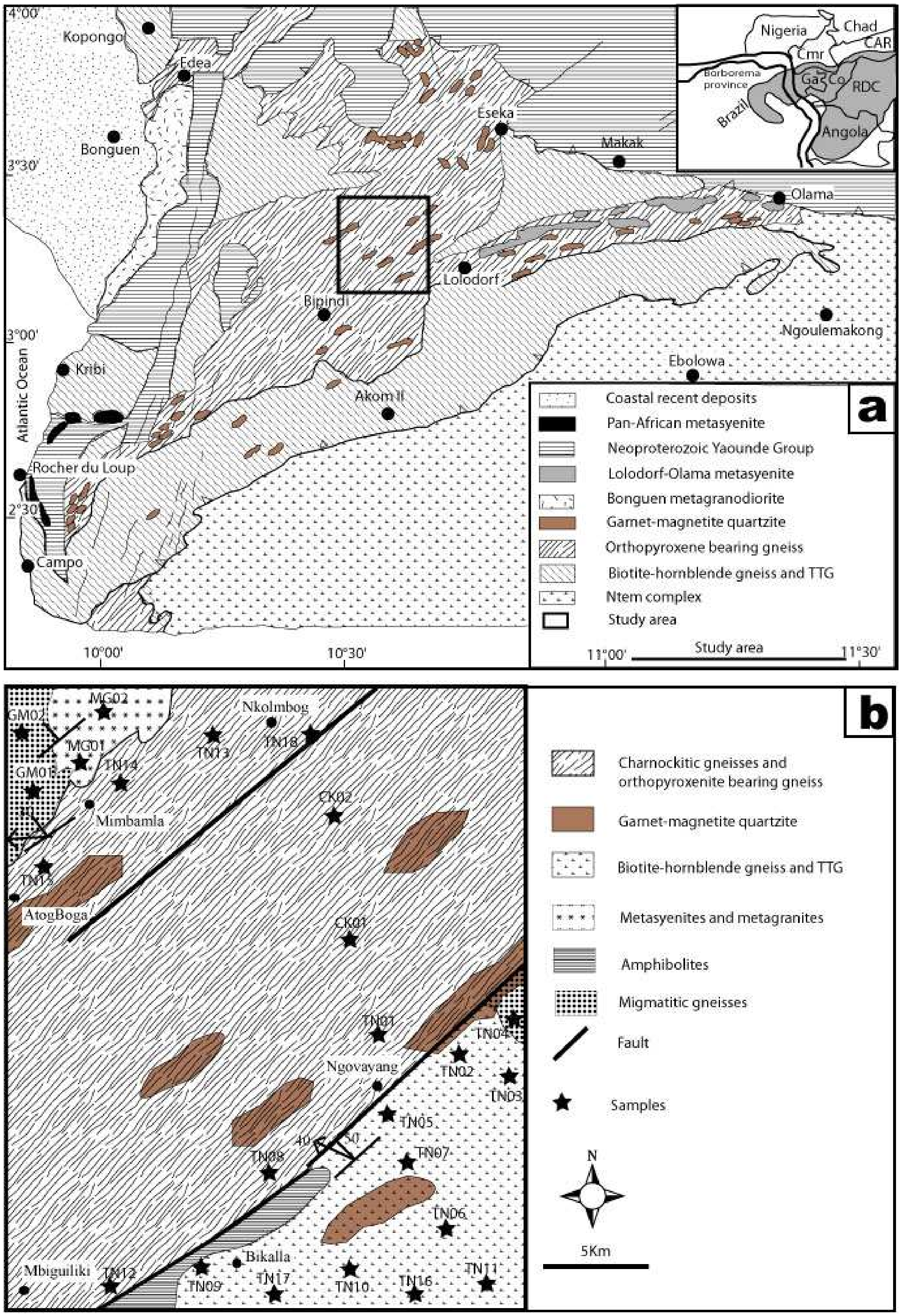

Figure 1: Geological map of wertern borderd of Congo craton in Cameroon. Maurizot 2000, modified by Nsifa et al (2013), Messi et al., (2014)

3 PETROGRAPHY

Figure 1b shows the different sampling points of granitoids of the explored domain. These formations are laid out as slabs on the water bed, as blocks on the ground or on the flanks of a hill. They are more or less stratified, showing medium grains (one to two mm) alternating with extremely fine grain levels.

The orthogneisses show enrichment in biotite and amphibole. Their mineralogical composition is: quartz, plagioclase, biotite, hornblende, zircon as primary minerals; apatite, chlorite, epidote, garnet and zircon, as secondary minerals. Potassic feldspar is rare or absent. The texture is heterogranular granolepidoblastic. The latter is due to the presence of large plagioclases of 1 to 3 mm diameters, moulded by a finely crystallized quartzo-micaceous framework

The migmatic gneisses are clear and more or less granitized. They are essentially composed of white minerals to which they owe their tint. They appear regularly altered at the outcrop surely due to the presence of feldspars.

The clear centimentric beds are constituted of feldspars, quartz and garnet. The dark beds are rich in micas and amphibole. The texture is heterogranular granoblastic marked by the presence of quatz, plagioclases and accessorily garnet, biotite, potassic feldspar and amphibole.

The charnockitic gneisses present a more or less clear metamorphic stratification. These rocks contain orthopyroxene, associated with respect to assemblages to biotite, sometimes amphibole, garnet and opaque minerals to which white minerals are added (quartz, plagioclase, potassic feldspar).

The metagranites are most usually grounded or really mylonitized and have a composition of gneiss and two micas, biotite appears abundant. The two micas (biotite and muscovite) are usually arranged in epitaxic groups. They both show clean traces of cataclase. Associated to an assemblage of finely polycrystalline quartz, they mould fresh plagioclases having absolutely all the characters of those described in the previous facies ([8].

4 MATERIALS AND METHODS

Samples meant for chemical analyses were prepared by ALS Geochemistry Cameroon. Major elements were analysed by X-ray fluorescence (XRF) using a hand held Phillips PW 1840 XRF. Trace elements and rare earth elements were analysed by a spectrometry coupled with plasma induction (ICP-MS) using a Vg-Plasma Quad STE ICP mass spectrometer in the ALS laboratory in Ireland. The samples were dissolved in a Teflon bomb at high pressure using a mixture of 1/1 HF and $HClO_4$ at 180°C, then carried in a solution of HNO_3 under standard internal conditions. After dissolving in HF-$HClO_4$, the samples were subjected to a mixture of HNO_3, 6NHCl and HF and later diluted. These solutions were measured 24h after dilution to prevent the absorption of HFSE on the cock of the sample container. Analytical errors are 1% for major elements, between 5% and 10% for trace elements, 5% for REE, > 10ppm and 10% for REE < 10ppm. The analytical results were interpreted using geochemical softwares [23]. Comparative studies carried out with gneiss TTG from other regions of the world (Ntem, Nûk, Amitsoq, Laxford Bridge, and Hillion).

5 RESULTS

5.1 MAJOR ELEMENTS

The metamorphites of the Ngovayang massif have an acidic composition (SiO_2 = 61.55-73.20%). These rocks are also poor in ferromagnesians (Tab. 1). The Fe_2O_3+MgO+MnO+TiO_2 sum varies from 3.16% to 4.87% with an Mg# varying from 36.15 to 50.77 in orthogneisses. This sum varies from 1.99 to 10.31 for an Mg# of 20.5 to 37.6 in charnockitic gneisses; from 3.15 to 4.24 for an Mg# of 33.3 to 43.8 in metagranites and of 2.23 to 2.38 for an Mg# of 15.9 to 25.5 in migmatites. Al_2O_3 contents are high (14.01% to 15.97%). The metamorphites of the Ngovayang massif are also characterized by their high Na_2O content (3.79%-6.47%) as opposed to their low K_2O (1.86-3.31%) content and their Cao content (1.47-2.70%). With the exception of migmatites, where K_2O content is clearly higher than that of Na_2O, and the CK02 sample where the CaO content is higher than that of Na_2O. Such percentages show that the potassic feldspar must mostly be concentrated in the biotite, in the rare microcline crystals and in antiperthite sparks. These results are in accord with the petrographic data which showed the scarcity of alkaline feldspars and the predominance of sodic plagioclase. Sample CK02 and in orthogneisses, the Na_2O/K_2O ratio is greater than two 2. According to [24] and [25], such a value of this ratio characterizes gneisses of tonalitic, trondhjemitic or granodioritic tendency; as shown by the diagrams of ([26], Fig. 2) where these rocks fall in the field of trondhjemites/tonalities. The other formations are distributed between the granodiorite and granite fields. In the Harker diagrams, the major elements have a tendency of diminishing with an increase in SiO_2 (Fig. 3).

The normative triangular diagram of O'connor (Fig. 4a) valid only for rocks with more than 10% of normative quartz precises the geochemical nature of the metamorphites of the Ngovayang massif. The orthogneisses are distributed in the trondhjemite domain, the migmatitic gneisses in the field of granites, the metagranites in the field of granodiorites while the charnockitic gneisses are distributed in the granodiorite and tonalite fields. The polygon in the diagram by [27] shows the site where the points of the greater majority of archean gneisses are distributed; those of the Ngovayang massif are also part of it. This is even more pronounced, considering the diagram of [28], modified by [29], which helps in considering the K_2O content in the biotite (Fig. 4b). Diagrams drawn based on the chemical elements affirm the conclusions obtained based on the normative diagrams. The SiO_2 to K_2O rectangular diagram of Ewart (1982) (Fig, 4C), on which points representing metamorphites of the Ngovayang massif fall in the calco-alkaline domain. The same tendency is noticed in the AFM triangular diagram [30], where the samples are placed in the field of calco-alkaline rocks (Fig. 4d). The Q-Ab-Or normative triangle (Fig. 4e) and the K-Na-Ca triangle (Fig. 4f) of [31] confirm the trondhjemitic nature of the orthogneisses of the Ngovayang massif, while the other formations follow a calco-alkaline trend. These are based on the relative low K_2O content of trondhjemitic suites to distinguish them from classic calco-alkaline suites.

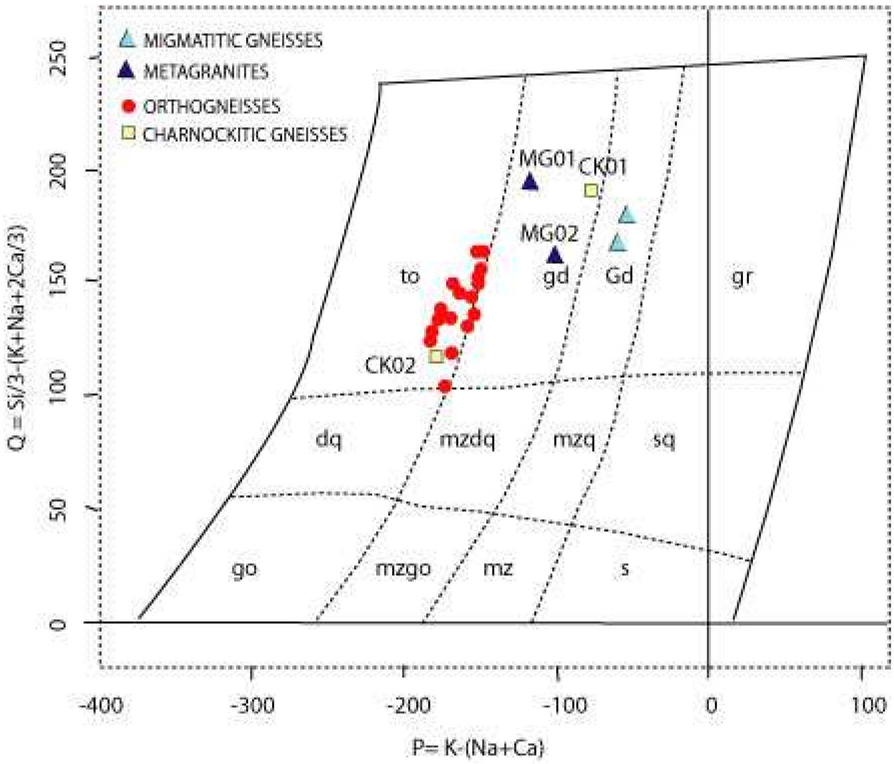

Figure 2: Diagram of Lebon and Lefort showing the protoliths of the granitoids of the Ngovayang area

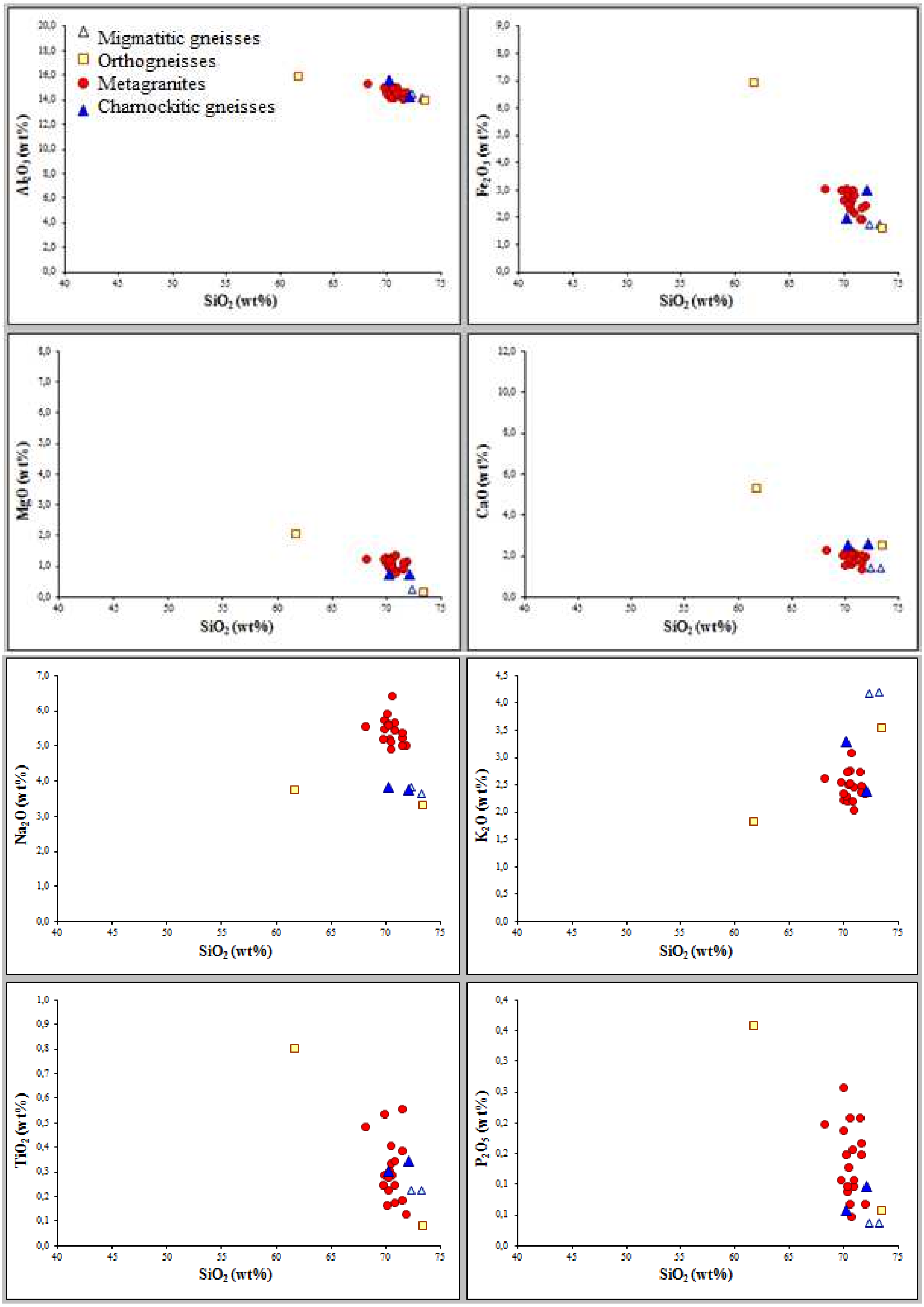

Figure 3: Harker diagrams for the principal major elements of the granitoids of the sector of study

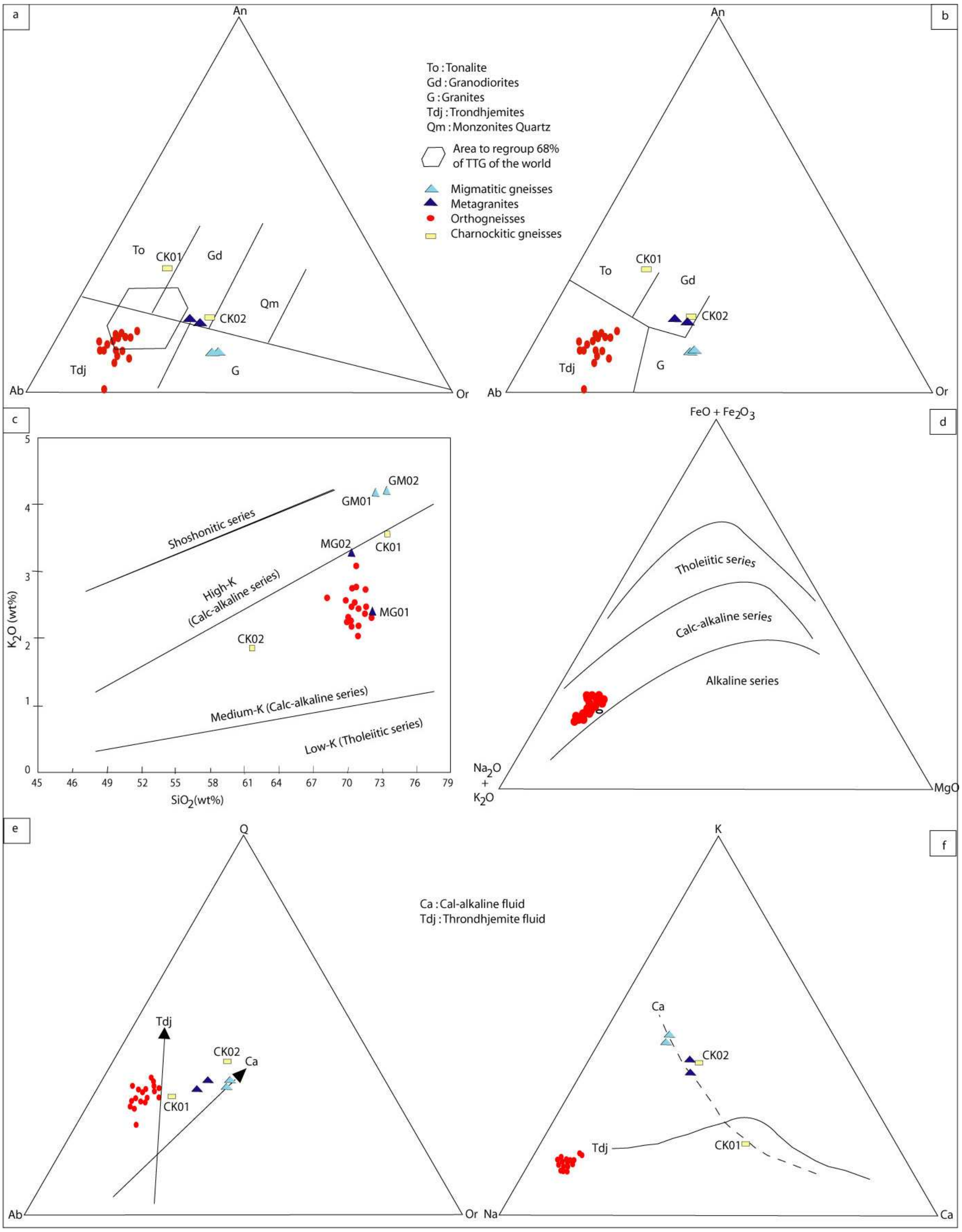

Figure 4: An-Ab-Or normative diagrams of a) [28] and b) [28] modifiedby [29]; c) SiO_2 vs. K_2O of [32]; d) AFM diagram of [30], diagrams that help to distinguish the classic calco-alkaline line from the typical trondhjemitic line of [31]; e) Q-Ab-Or ; f) K-Na-Ca

5.2 TRACE AND RARE EARTH ELEMENTS

The Harker diagrams (Fig. 5) show the variation of trace elements with SiO_2. Rb varies from 21 to 163 ppm. The variation may be explained as due to the mobility of Sr during metamorphism. Ba varies from 302 to 2350 ppm, the Zr from 34 to 337 ppm meanwhile Ni varies from 1 to 36 ppm. The orthogneisses are characterized by high Sr (301 to 810 ppm) contents in accordance with [34] and [35] which show that these contents are usually higher than 300ppm and in La(La_N = 44.22). On the other hand, Yb (0.3-0.7 ppm) and Y (4-12 ppm) contents are low, respectively lower than 0.7 and 17ppm for these rocks. This is surely the cause of the high $(La/Yb)_N$ and Sr/Y ratios. The high Al_2O_3 and Sr contents are coherent with the abundance in plagioclase. On the contrary, low content in incompatible elements (Rb=29-67ppm, Th=1-8ppm, La=9.7-11.2ppm) is related to low potassium content. The high $(Th/Nb)_N$ and $(La/Nb)_N$ ratios (normalized with the primary mantle) (2.7-419.4 and 1.37-105.36 respectively), are in the similar range of orogenic calco-alkaline rocks, in accord with the poorly potassic character. The content in elements such as Zr and Nb shows that the orthogneisses are similar to calco-alkaline plutons of oceanic subduction zones (low zircon content and low Nb/Zr ratio), apart from samples TN10, TN14, TN16 and TN18 which are similar to post-collisional calco-alkaline granitoids ($(Nb/Zr)_N$ ratio generally greater than 1), [36].

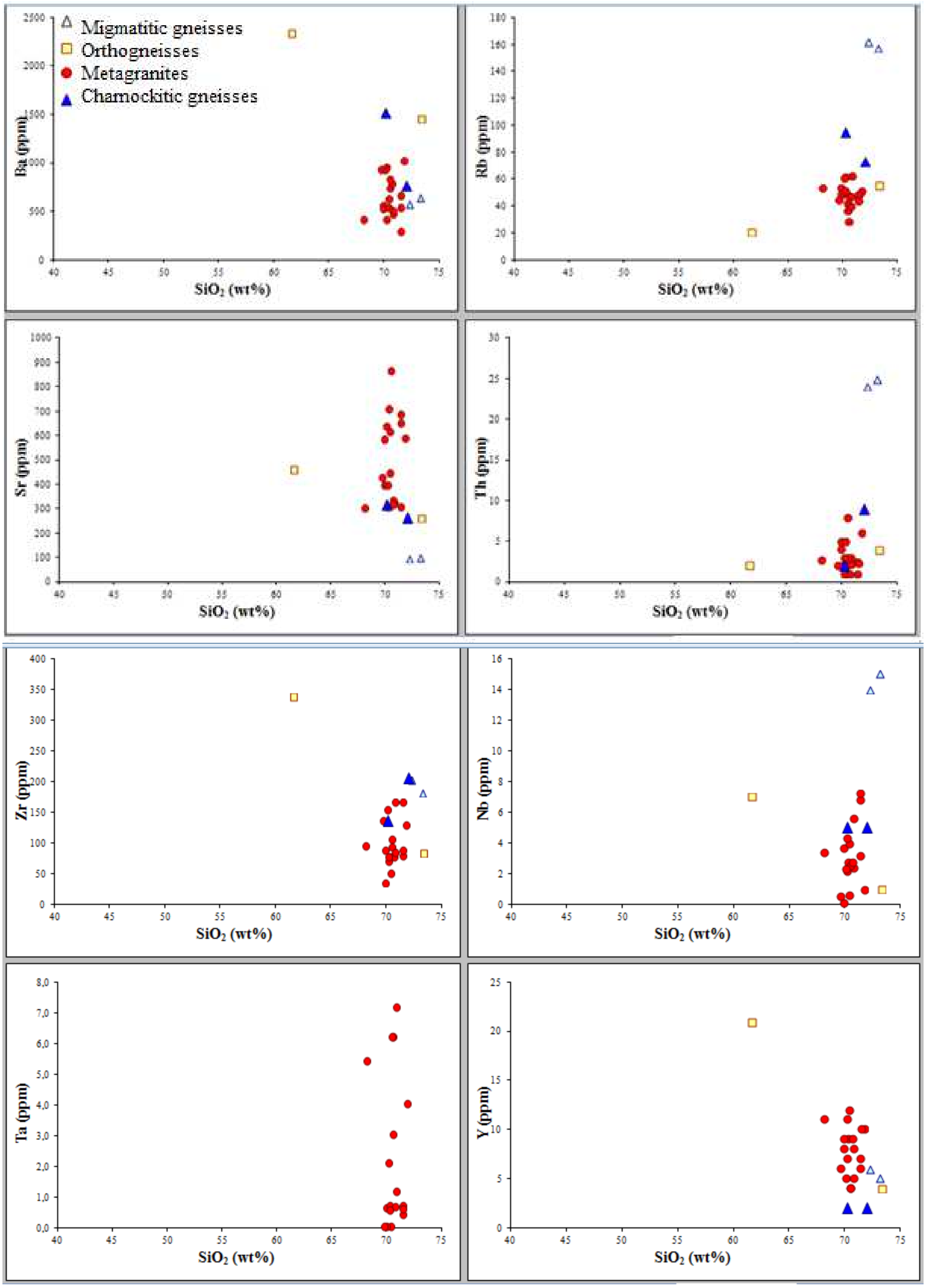

Figure 5: Harker diagrams for trace elements with respect to SiO_2

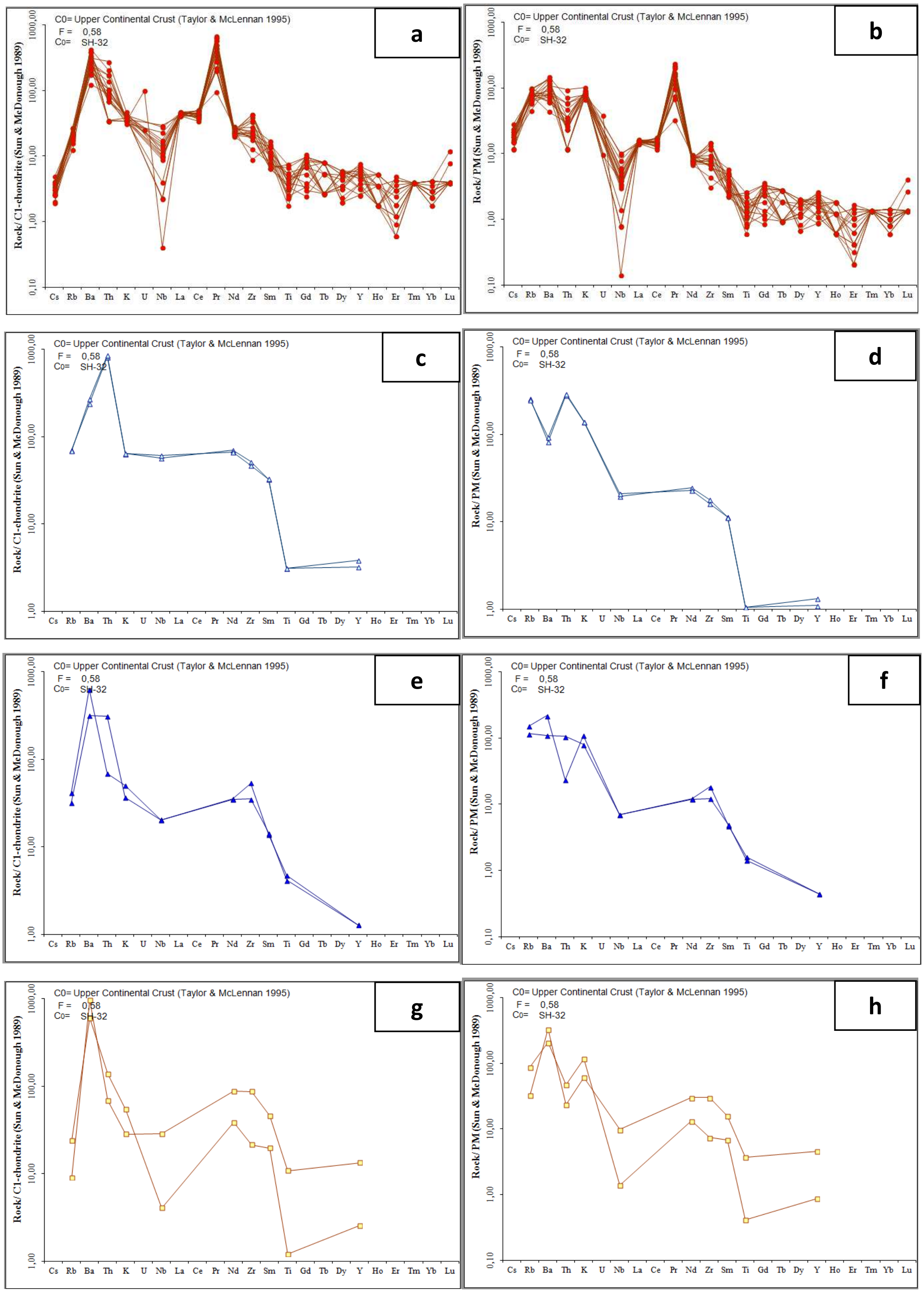

Figure 6: Rare earth spectra normalized with respect to chondrites and primary mantle of Sun and McDonough, 1989: orthogneiss (a and b); magmatic gneisses (c and d); metagranites (e and f); charnockitic gneisses (g and h)

Figure 6 shows the look of the rare earth spectra of the metamorphite samples of the Ngovayang massif, normalized using Chondrites by Sun and [37] and the primary mantle. For the orthogneisses, we notice low contents in heavy rare earth elements (Yb<0.7 ppm and Y<12ppm) and high contents in light rare earth element (La_{avg}= 15.85 ppm), without any significant anomaly in Europium (Eu/Eu*=1.17) but a negative anomaly in Ti and Nb. The impoverishment in heavy rare earth elements is important; hence the downward convex form in the shape of a spoon.

6 Discussion

6.1 Mobility of elements

The most mobile elements during granulitic metamorphism are alkalis (Rb and Cs and eventually K) as well as Th and U. Figures 7 and 8 shows the difference between formations of high grade metamorphism and those of low grade metamorphism. Granulitic formations are impoverished in Rb. This mobility is measured with respect to K and Sr which seem relatively mildly mobile. In compiling numerous data on granulites, [38] showed that for a lower than 1% in K content, granulites were rapidly impoverished in Rb, as compared to K, signifying that the more the rock is low in potassic minerals (particularly potassic feldspars) the more important its impoverishment. One of the most important characteristics of the granulite facies, low large ion lithophile elements (LILE) content to which belong K and Rb, is found in our rocks.

Th content is also low in our samples. The trace element spectra of the formations of the sector of study indicate strong anomalies in Th (Fig. 6). The charnockitic gneisses (CK01) are also impoverished in Rb in comparism to K. The dehydration reactions which occur during the passing from the amphibolite to the granulite facies, are designated as mechanisms responsible for the impoverishment in LILE. The mobilized fluids may be susceptible of transporting these elements (Heier, 1973). The migmatitic gneisses have K/Rb ratios close to the average of the continental crust (240 to 250) determined by [40] and [41]. The most mobile elements during metamorphism are mainly Rb and Th. The impoverishment of these elements in orthogneisses and the CK02 sample is without a doubt the result of granulitic metamorphism. Figure 7 shows that some rocks (CK01) have high K content. These samples do not present any anomaly in K, although the relative losses in Rb. Concerning Sr, we observe a relative immobility of this element in orthogneisses and in CK01 charnocktic gneisses. The harker diagrams show that the behavior of alkalis in metagranites is normal. The loss on ignition of these acidic formations is lower than 1%. This indicates that alteration phenomena such as sericitisation and kaolinisation of feldspars, chloritisation of biotites etc. are almost inexistent. These metagranites have Rb/Sr ratios greater than 0.1, which are close to the average value of the crust.

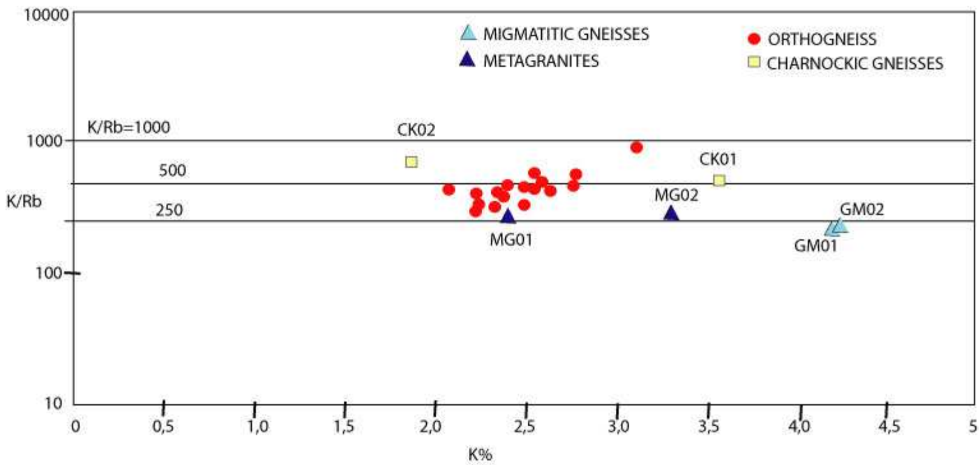

Figure 7: K/Rb vs K diagram of the granitoids of the Ngovayang massif

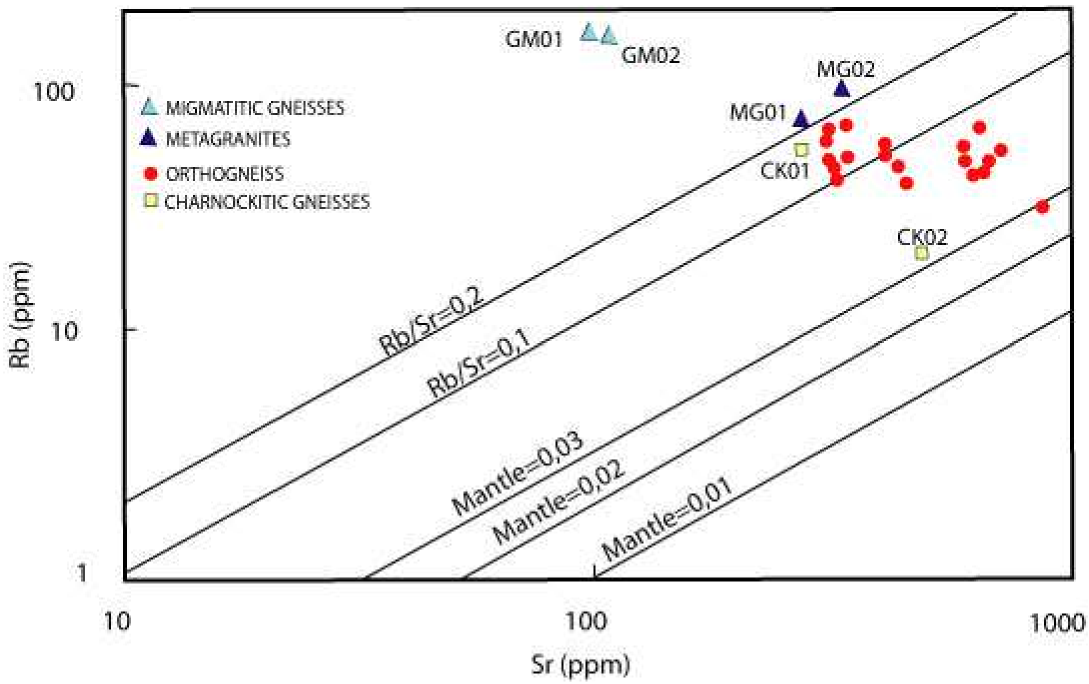

Figure 8: Rb vs Sr diagram of the granitoids of the Ngovayang massif

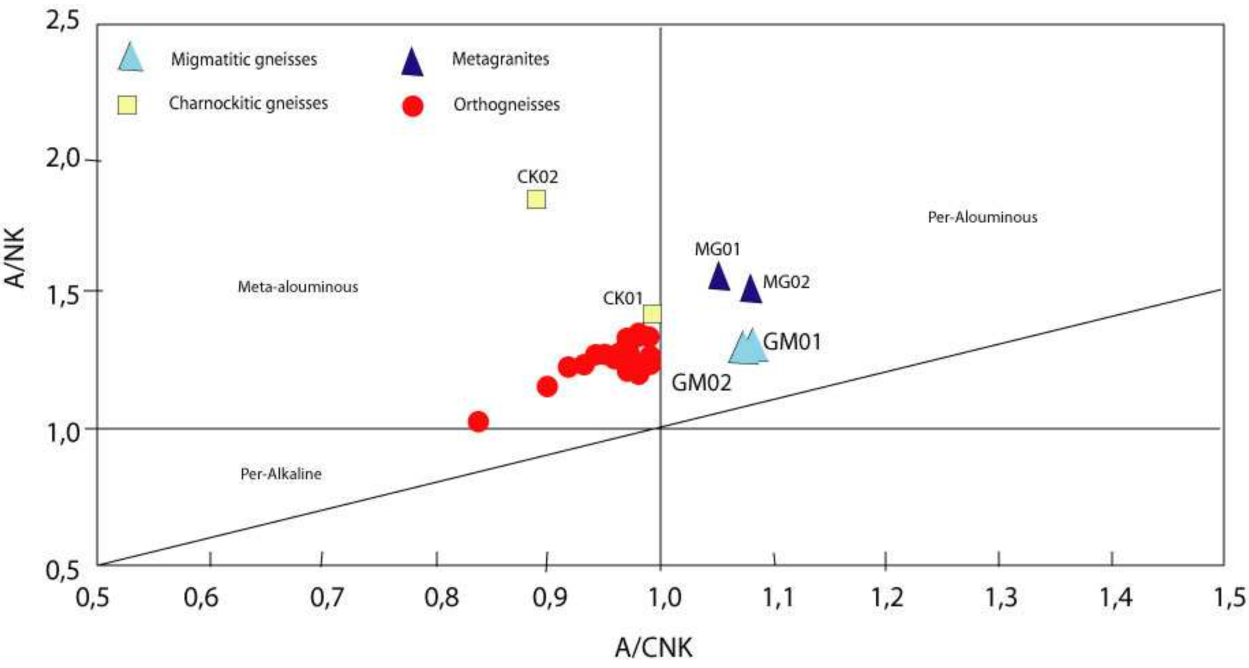

Figure 9: Shang indice showing the granitoids of the Ngovayang massif

6.2 SOURCES AND GEOTECTONIC FRAMEWORK

6.2.1 ORTHOGNEISS

The general character of major and trace elements of the orthogneisses of the Ngovayang massif are similar to those of the typical archean tonalitic, trondhjemitic and granodioritic (TTG) formations across the world, independent of their geographic position ([31], [42], [43], [44], [29], [25], [45], [46], [47], [27], [48], [49], [50], [15], [51], [52], [5], [53], [54], [55].

Indeed, the comparism made between the gneisses of the Ngovayang massif and the tonalitic, trondhjemitic and granodioritic archaean formations of the Ntem [15] found more to the south-east in the craton, shows a perfect similarity between the two assemblages. The geochemical diagrams clearly illustrate the identity in composition between the orthogneisses of the Ngovayang massif and the Archean TTG of Sangmelima [57]. Table 2 helps to better compare these trondhjemitic rocks as defined by [29]. It's thus clear that these have real trondhjemitic affinities. The Ntem archean formations belong to a typical trondhjemitic line [15] such as defined by [31] and [29]. Those of the Ngovayang massif are also in this domain.

Their high Al_2O_3 content is similar to Alumina-rich trondhjemites « High Al_2O_3 » of Barker and Arth, 1976; to « High Al_2O_3 » archean TTGs of the Ntem ([50], [15]) and infact of orthogneisses of the Ngovayang massif, metaluminous gneisses (Fig. 10), as confirmed by the calculation of the Shand indice (Maniar and Piccoli, 1989). The orthogneisses of the Ngovayang massif meet those of the Ntem in the evolution curve of the trondhjemitic line, hence showing their similar belonging to this type of differenciation.

The rare earth spectra are fractionated and clearly show an appearance in the shape of a spoon. This appearance is in accord with those of the TTGs of the rest of the world [58] with a negative anomaly in Ti and Nb. As to regards the K/Rb, Rb/Sr and Eu/Eu* ratios, they are very similar to those found in the Sangmelima TTGs [57] and Meiganga [55]. The high alumina and Sr content indicate a high solubility of plagioclases in the liquid. Low contents in incompatible elements is a characteristic of the magmatic fluid and not the result of a dilution of trace elements by a cumulative phase [36] as illustrated by figure 11 where the orthogneisses are in the field of TTG and not in that of actual arc granitoids. These characters help in attributing orthogneisses of the Ngovayang massif to the TTG group of the Ntem. It will be possible from the regional point of view to agree that the orthogneisses of the Ngovayang massif would be continuity of the TTGs of trondhjemitic affinity, of the Ebolowa region.

6.2.2 CHARNOCKITIC GNEISSES

6.2.2.1 SAMPLE CK02

The CK02 charnockitic gneiss is of tonalitic composition with 61.55% of silica. It is a meta-aluminous rock (A/CNK=0.89; Fig. 9). In the Qtz-Ab-Or diagram (Fig. 4e), it follows the trondhjemitic trend, meanwhile in the K-Na-Ca diagram (Fig. 4f), it is found in the zone common to calco-alkaline and trondhjemetic lines. The multi-element spectrum (Fig. 6g&h) indicates anomalies in Rb and in Th characterizing granulitic facies of charnocktic gneiss. The charnockitic gneiss is relatively rich in incompatible elements such as Ba, Nd and Sm. The Yttrium content is about 4.5 times higher than that of the mantle suggesting the origin of this gneiss as being different from that of CK01. Indeed, in the Sr/Y to Y diagram, it is found out of the field defined by archean TTGs and adakites. It would have thus formed by partial melting from a source not containing garnet and eventually hornblende as well.

6.2.2.2 SAMPLE CK01

The CK01 charnockitic gneiss contains 73.30% of SiO_2, is meta-aluminous (Fig. 9) and of granodioritic composition (Fig. 2) It belongs to a calco-alkaline suite (Fig. 4e and 4f). Papon (1973) describes parageneses bearing amphibole, diopside and hypersthene, signifying that these formations are in conditions of metamorphism of the facies of hornblende bearing granulites. Thus, the rare earth spectrum (Fig. 6g&h) indicates a relative impoverishment in Rb as compared with K. The negative anomalies in Nb and Ti are important. The Yttrium here is also low in quantity as in migmatitic gneiss. On the contrary, the high enough (Sr/Y) ratio (higher than that of TTGs) suggests a differentiation process close to that of TTGs, for these rocks. This character differentiates CK01 charnockitic gneiss from CK02 charnockitic gneiss.

6.2.3 MIGMATITIC GNEISS

These are homogenous rocks composed of dark and white millimetric beds. We think that the chemistry of these rocks permits the characterization of its protolith.

The GM01 and GM01 migmatitic gneisses respectively contain 72.22 and 73.20% of silica. They are of granitic composition (Fig. 2) and peralouminous (A/CNK=1.06). It contains 1% of normative corundum.

These formations follow a calco-alkaline differentiation (Fig. 4e&f). Comparing them with the classification of [59], their composition is close to the CA2 type (Fig. 11).

The spectra (Fig. 6c&d) indicate good similarities for most of the elements, except Sr and P, to a lower degree. No impoverishment in Rb as compared to K is observed, thus confirming medium grade metamorphic conditions. These migmatites have a higher Nb content and a lower Sr content. The low proportion in Yttrium surely indicates an impoverishment in heavy rare earths. In figure 11, these rocks fall in a field, not far from that of TTGs. The product of the melting from which these rocks form, is probably in equilibrium with residues containing garnet. The peralouminous nature of these formations (1% normalized corundum) helps considering, even in part, an origin by melting of the sediments.

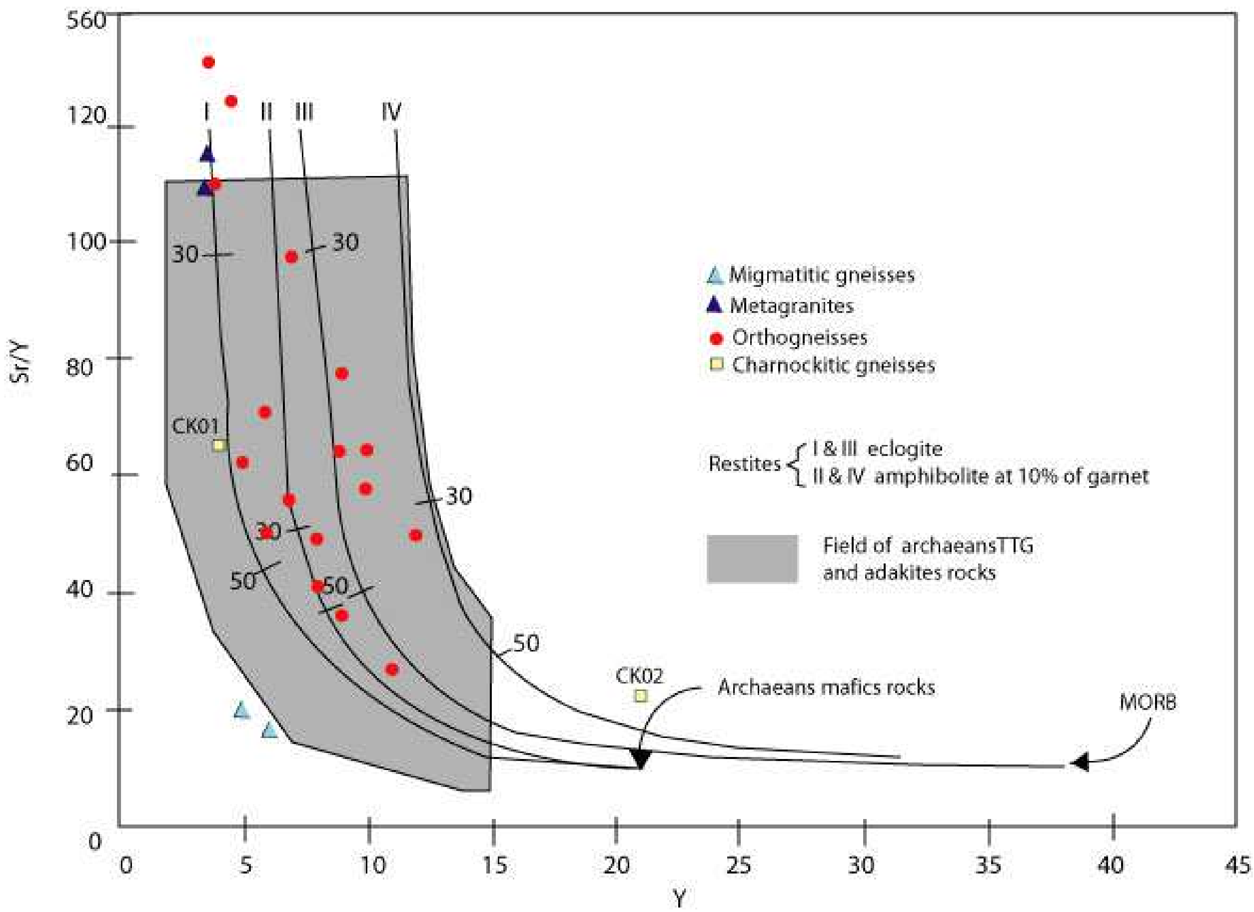

Figure 10: Sr/Y vs Y diagram showing the sources of the granitoids of the sector of study.

6.2.4 METAGRANITES

The MG01 and MG02 samples respectively contain 71.98 and 70.12% of silica. They have K_2O/Na_2O ratios lower than 1%. These formations are poorly peralouminous (Fig. 9) and of granodioritic composition (Fig. 2). From field observations, MG02 would be the product of the melting of MG01. They belong to a calco-alkaline series (Fig. 4c, 4e and 4f) and are closer to the CA2 type ([59]; Fig. 11), given the high Rb/Y ratios. The spectra (Fig. 6e&f), also seem to confirm this character. The product of the melting and the parent rock, have similar spectra with a negative anomaly in Th and P, the latter being of lower importance. The high Sr/Y ratio for these formations effectively indicates that the latter were much fractionated during the differentiation.

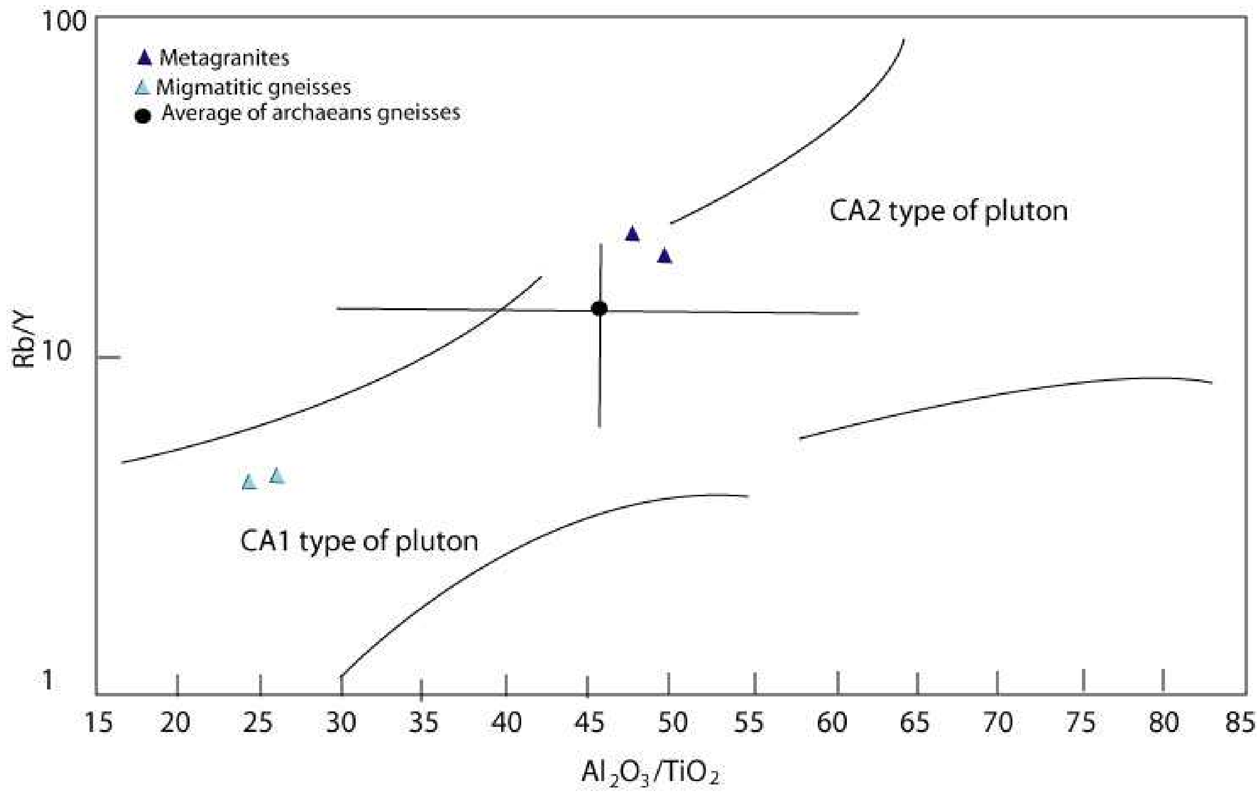

Figure 11: Rb/Y vs Al_2O_3/TiO_2 diagram of [59], comparing the types of plutons

Table 1: Majors and traces elements of granitoids of Ngovayang massif

Samples	Orthogneiss								
	TN01	TN02	TN03	TN04	TN05	TN06	TN07	TN08	TN09
SiO_2	69.87	70.31	70.79	70.2	70.5	70.09	71.41	69.86	70.7
Al_2O_3	14.75	14.77	14.98	15.01	14.23	15.16	14.07	14.5	14.5
Fe_2O_3 (t)	2.62	2.98	2.19	2.82	2.66	3.06	1.94	2.64	3.01
MgO	1.34	1.35	0.94	1.03	1.34	1.12	0.98	1.22	0.86
CaO	2.21	2.09	2.16	2.18	1.64	2.28	1.73	1.62	2.03
Na_2O	5.8	5.24	5.73	5.68	6.47	5.95	5.28	5.52	5.5
K_2O	2.25	2.52	2.48	2.21	3.1	2.31	2.49	2.35	2.22
TiO_2	0.29	0.31	0.18	0.23	0.29	0.17	0.19	0.54	0.25
P_2O_5	0.19	0.13	0.1	0.09	0.05	0.15	0.17	0.26	0.16
MnO	0.08	0.03	0.02	0.03	0.08	0.02	0.05	0.03	0.03
LOI	0.7	0.84	0.61	0.42	0.66	0.6	0.71	0.78	0.63
Sum	100.1	100.57	100.18	99.9	101.02	100.91	99.02	99.32	99.89
Cs	0.67	0.91	0.58	0.71	0.53	0.49	0.76	0.38	0.76
Rb	54	49	63	62	29	61	48	49	47
Ba	571	638	480	963	757	944	552	537	795
Sr	400	710	330	310	870	640	690	586	335
Th	5	5	3	1	8	2	1	4	1
U	0.8	0.2	-	-	-	-	-	-	-
Zr	34	76	165	69	106	153	165	87	76
Hf	4.01	3.06	3.06	2.34	3.98	4.23	4.34	3.48	3.67
Ta	0.67	0.05	1.21	0.73	6.23	2.12	0.43	0.05	0.68
Y	8	9	8	11	4	5	7	9	9
Nb	0.1	2.76	2.42	2.15	2.5	2.34	3.2	3.68	2.77
Sc	15	4	9	5	4	11	6	10	2

Cr	63	84	101	50	77	115	94	115	125
Ni	5	24	30	16	31	8	19	9	29
Co	2.3	1.1	2.2	1.8	1.2	0.9	1.1	1.2	1.6
V	10.8	99	77.2	96.5	64	23	50.6	152	98
Ga	0.07	5.01	4.06	2.51	2.26	2.03	3.02	2.34	3.67
Zn	26	35	23	21	23	47	32	13	21
Cu	17.85	25	17.1	25	12.95	35	29.9	45	42.6
La	10.3	11.1	9.8	10.6	10.3	9.7	11	9.8	10.5
Ce	25.3	22.3	20.7	30.3	30.29	26.59	27.32	31.2	26.8
Pr	43	32	28	9	47	19	21	19	43
Nd	11.6	9.7	11.4	13.1	12.2	10.3	10.8	12.5	11
Sm	2.2	1.5	1.5	2.1	2.6	1.6	1.8	2.3	1.2
Eu	0.6	0.5	0.7	0.7	0.7	0.7	0.6	0.6	0.7
Gd	1.4	2	0.7	1.5	0.7	2.2	2	0.61	0.5
Tb	0.1	0.1	0.3	0.1	0.3	0.2	0.1	0.1	0.2
Dy	1.2	1.5	1.5	0.9	0.5	1.3	1.5	0.9	0.8
Ho	0.1	0.1	0.3	0.3	0.3	0.1	0.2	0.2	0.1
Er	0.6	0.8	0.2	0.5	0.5	0.2	0.4	0.7	0.15
Tm	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Yb	0.6	0.7	0.4	0.3	0.5	0.3	0.4	0.5	0.7
Lu	0.1	0.3	0.1	0.1	0.1	0.1	0.2	0.1	0.1
Eu/Eu*	1.04	0.88	2.08	1.20	1.58	1.14	0.96	1.54	2.75
Mg#	50.33	47.30	45.95	41.98	49.95	42.03	50.02	47.79	36.14
K	18677	20919	20587	18345	25734	19176	20670	19508	18428
Ti	1728.1	1847.2	1072.	1370.5	1728.	1013.	1132.2	3217.86	1489.7
P	829.27	567.39	436.46	392.81	218.23	654.69	741.98	1134.79	698.33
A/CNK	0.92	0.97	0.93	0.95	0.84	0.92	0.97	0.99	0.96
F_2O_3+MgO+TiO_2+MnO	4.33	4.67	3.33	4.11	4.37	4.37	3.16	4.43	4.15
K_2O/NaO	0.38	0.48	0.43	0.38	0.47	0.38	0.47	0.42	0.4
Na_2O/K_2O	2.57	2.07	2.31	2.57	2.08	2.57	2.12	2.34	2.47

Table 1 : (Continued)

Samples	Orthogneiss								
	TN10	TN11	TN12	TN13	TN14	TN15	TN16	TN17	TN18
SiO_2	70.4	71.76	70.44	69.65	71.4	68.08	70.74	70.18	71.42
Al_2O_3	15.04	14.6	15.03	15.01	14.25	15.34	14.53	14.22	14.62
Fe_2O_3 (t)	2.32	2.46	2.51	3.02	1.94	3.06	2.85	2.52	2.38
MgO	1.13	1.21	1.06	1.31	1.01	1.3	1.43	1.28	1.18
CaO	2.28	2.06	2.14	2.11	1.42	2.34	1.81	1.91	2.07
Na_2O	4.94	5.05	5.19	5.26	5.41	5.61	5.49	5.64	5.07
K_2O	2.77	2.36	2.54	2.57	2.75	2.63	2.06	2.76	2.38
TiO_2	0.41	0.13	0.34	0.25	0.56	0.49	0.35	0.28	0.39
P_2O_5	0.07	0.07	0.21	0.11	0.21	0.2	0.11	0.1	0.15
MnO	0.01	0.02	0.04	0.08	0.09	0.02	0.04	0.02	0.05
LOI	0.65	0.66	0.61	0.68	0.75	1.07	0.73	0.97	0.64
Sum	100.0	100.38	100.11	100.05	99.79	100.14	100.1	99.88	100.35
Cs	0.58	0.63	0.37	0.48	0.63	0.71	0.51	0.59	0.48
Rb	42	51	37	45	49	54	40	51	44
Ba	557	1040	847	939	302	433	516	425	676
Sr	620	590	450	430	308	305	317	399	655
Th	2	6	3	2	2.5	2.7	2.2	3	2.3
Zr	49	129	93	135	78	95	83	76	87
Hf	3.08	3.52	4.21	3.73	4.02	3.75	3.13	4.13	4.01
Ta	6.23	4.05	3.06	0.04	0.72	5.46	7.21	0.58	0.63

Y	12	10	4	6	6	11	5	7	10
Nb	3.99	0.98	0.57	0.55	6.8	3.4	5.6	4.34	7.21
Sc	18	5	7	6	9	5	7	5	4
Cr	53	148	39	278	10	12	43	65	72
Ni	33	36	7	13	20	16	18	21	17
Co	1.3	2	3.8	0.5	6	4	7	6	5.4
V	28.6	108	101.5	98.3	87	103	49	63	88
Ga	1.41	5.43	4.96	7.56	4.35	6.23	6.75	4.32	8.86
Zn	8	49	22	22	33	54	15	35	28
Cu	46.4	18.7	28.1	15.2	18	23	14	14	25
La	10.3	11.2	11.1	10.6	10.6	10.2	10.8	11.1	9.7
Ce	23.9	25.3	26.6	26.65	23.32	28.1	27.4	29.32	24.3
Pr	62	37	66	38	57	48	61	56	27
Nd	9.3	10.4	12.3	12.3	10.4	9.6	11.2	10.9	10.1
Sm	1.2	1.4	2.1	1	1	1.1	1.6	1	1.8
Eu	0.3	0.6	0.4	0.6	0.7	0.7	0.4	0.7	0.6
Gd	1.4	1.8	1.1	1.7	2	2	1.4	1.7	0.8
Tb	0.2	0.3	0.1	0.3	0.3	0.3	0.3	0.1	0.1
Dy	1.1	1.3	0.9	0.5	0.6	1.3	1.5	1.5	0.8
Ho	0.1	0.2	0.2	0.1	0.2	0.2	0.1	0.3	0.1
Er	0.7	0.3	0.3	0.2	0.2	0.1	0.1	0.5	0.5
Tm	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Yb	0.7	0.4	0.4	0.5	0.7	0.7	0.4	0.5	0.5
Lu	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Eu/Eu*	0.70	1.15	0.80	1.40	1.51	1.44	0.81	1.63	1.52
Mg#	49.10	49.35	45.55	46.21	50.77	45.70	49.85	50.15	49.55
K	22994	19591	21085	21334	22828	21832	17100	22911	19757
Ti	2443	774	2026	1489	3337	2919	2085	1668	2324
P	305	305	916	480	916	872	480	436	654
A/CNK	0.98	0.99	0.99	0.98	0.98	0.94	0.99	0.9	0.99
F_2O_3+MgO+TiO_2+MnO	3.87	3.82	3.95	4.66	3.6	4.87	4.67	4.1	4
K_2O/NaO	0.56	0.46	0.48	0.48	0.5	0.46	0.37	0.48	0.46
Na_2O/K_2O	1.78	2.13	2.04	2.04	1.96	2.13	2.66	2.04	2.13
K/Rb	547	384.	569	474	465	404	427	449	449
Rb/Sr	0.06	0.14	0.08	0.10	0.16	0.18	0.13	0.13	0.15

Table 1 : (Continued)

Samples	Charnockitic gneisses		Metagranites		Migmatitic gneisses	
	CK01	CK02	MG01	MG02	GM01	GM02
SiO_2	73.30	61.55	71.98	70.12	72.22	73.20
$Al2O_3$	14.01	15.97	14.33	15.71	14.53	14.21
Fe_2O_3 (t)	1.61	6.94	3.01	1.98	1.79	1.78
MgO	0.21	2.11	0.76	0.78	0.31	0.17
CaO	2.59	5.39	2.70	2.65	1.50	1.47
Na_2O	3.34	3.79	3.77	3.85	3.86	3.69
K_2O	3.57	1.86	2.41	3.31	4.20	4.22
TiO_2	0.09	0.81	0.35	0.31	0.23	0.23
P_2O_5	0.06	0.36	0.10	0.06	0.04	0.04
MnO	0.02	0.09	0.02	0.02	0.01	0.01
LOI	0.50	0.19	0.31	0.07	0.41	0.28
Rb	56.000	21.000	74.000	96.000	163.000	158.000
Ba	1463.000	2350.000	765.000	1528.000	576.000	652.000
Sr	260.000	463.000	264.000	319.000	95.000	101.000
Pb	9.000	9.000	13.000	11.000	26.000	26.000

Th	4.000	2.000	9.000	2.000	24.000	25.000
Zr	83.000	337.000	206.000	136.000	201.000	181.000
Y	4.000	21.000	2.000	2.000	6.000	5.000
Nb	1.000	7.000	5.000	5.000	14.000	15.000
Cr	18.000	41.000	15.000	22.000	11.000	17.000
Ni	1.000	23.000	4.000	9.000	1.000	3.000
Co	1.000	17.000	7.000	5.000	4.000	3.000
V	18.000	110.000	41.000	32.000	15.000	16.000
Ga	12.000	21.000	17.000	16.000	19.000	19.000
Zn	17.000	85.000	13.000	11.000	39.000	37.000
Cu	1.000	25.000	9.000	20.000	1.000	1.000
Nd	18.000	41.000	16.500	16.200	33.000	31.000
Sm	3.000	7.000	2.100	2.200	5.000	5.000
(Sm)n	19.608	45.752	13.725	14.379	32.680	32.680
FeO (t)	1.45	6.25	2.71	1.78	1.61	1.60
Mg#	20.5	37.6	33.3	43.8	25.5	15.9
K	29635.6	15440.4	20006.1	27477.3	34865.5	35031.5
Ti	536.3	4826.8	2085.7	1847.3	1370.6	1370.6
P	261.9	1571.3	436.5	261.9	174.6	174.6
A/CNK	0.99	0.88	1.04	1.06	1.06	1.06
A/NK	1.49	1.94	1.63	1.58	1.33	1.34
Na_2O/K_2O	0.93	2.04	1.56	1.16	0.92	0.87

Table 2: Comparative table of the chemical composition of the orthogneisses of the Ngovayang massif to that of trondhjemites

Chemical characteristics of trondhjemites according Barker (1979)	Chemical characteristics of orthogneiss of Ngovayang massif (18 samples)
$68\%<SiO_2<75\%$	70.43%
$Al_2O_3>15\%$ pour $SiO_2=70\%$ et $Al_2O_3<15\%$ pour $SiO_2=75\%$	14.70%
K/Na<0.5	0.38-0.5
A/CNK≈1	0.84-0.99
1,5<CaO<3%	2%
$4\%<Na_2O<5{,}5\%$	5.49%
$K_2O<2{,}5\%$	2.49%
2<FeO*/MgO<3%	2,25%

7 Conclusion

The study of the geochemical characters helped in differentiating the granitoids of the sector of study. This study brings out a progressive variation of the nature of the gneissic basement of this massif. In summary, the orthogneisses of the Ngovayang massif are poorly potassic calco-alkaline granitoids of trondhjemitic affinity. They present all the characteristics of TTG type of rocks of which the most possible context of formation is that of magmatism in subduction zones. Our new results show an analogy between the orthogneisses of the Ngovayang massif and the TTG of other regions in the world and the strong similarities between these units and the granitoids of trondhjemitic tendencies. The orthogneisses of the Ngovayang massif meet those of the Ebolowa on the evolution curve of trondhjemitic lines, thereby demonstrating their similar belonging to this type of differenciation. This character is a decisive argument in favour of the parentage between the orthogneisses of the Ngovayang massif and the TTGs of the Ntem complex which outcrop more to the South-East, in Ebolowa. The migmatites have a granodioritic composition and correspond to a calco-alkaline series. They have low Y content and are comparable to the CA2 type of pluton. This indicates that these formations originate from the melting of a source with the presence of garnet in the residues of melting similar to those which generate TTGs. Migmatitic gneisses seem to be the products of the sediments. CK01 charnockitic gneiss is of granodioritic composition. They possess highly fractionated spectra. These characters differentiate them from CK02 charnockitic gneiss (tonalitic) which would have formed from the partial melting of a source whose melting residue does not contain garnet. The formations of the sector of study present in a variable manner, no matter the domain, an impoverishment in LILE (Rb, Th and sometimes in K). These formations would originate from the high grade metamorphism of archaean charnockites of TTG composition or not, during the Eburnean orogeny which led to the emplacement of the Ngovayang massif.

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