Advances in Applied Sciences
2023; 8(1): 15-27
http://www.sciencepublishinggroup.com/j/aas
doi: 10.11648/j.aas.20230801.13
ISSN: 2575-2065 (Print); ISSN: 2575-1514 (Online)

Whole Rock Geochemistry and Geodynamic Evolution of Paleoproterozoic Gneisses, Ako'ozam-Njabilobe Area, Southwestern Cameroon

Christopher Fuanya[1, 3, *], Boniface Kankeu[2], Anthony Temidayo Bolarinwa[3], Rose Fouateu Yongue[4]

[1]Department of Geology, University of Buea, Buea, Cameroon

[2]Institute for Geological and Mining Research (IRGM), Yaounde, Cameroon

[3]Department of Geology, Pan African University Life and Earth Science Institute (PAULESI), University of Ibadan, Ibadan, Nigeria

[4]Department of Earth Sciences, University of Yaounde I, Yaounde, Cameroon

Email address:

Fuanya.christopher@ubuea.cm (Christopher Fuanya), bonifacekankeu@yahoo.fr (Boniface Kankeu), atbola@yahoo.com (Anthony Temidayo Bolarinwa), rfyongue@yahoo.fr (Rose Fouateu Yongue)

[*]Corresponding author

To cite this article:

Christopher Fuanya, Boniface Kankeu, Anthony Temidayo Bolarinwa, Rose Fouateu Yongue. Whole Rock Geochemistry and Geodynamic Evolution of Paleoproterozoic Gneisses, Ako'ozam-Njabilobe Area, Southwestern Cameroon. *Advances in Applied Sciences*. Vol. 8, No. 1, 2023, pp. 15-27. doi: 10.11648/j.aas.20230801.13

Received: January 1, 2023; **Accepted**: January 31, 2023; **Published**: February 14, 2023

Abstract: The Ako'ozam–Njabilobe area, which is part of the Nyong group, is characterized mainly by highly deformed gneisses that host amphibolites, and metadolerites as enclaves. The gneisses within the Ako'ozam-Njabilobe area were investigated to constrain their geotectonic environment as well as understand their geodynamic evolution within the Nyong group. Three litho-types of gneisses outcrop within the Ako'ozam-Njabilobe area, consisting of horblende-biotite, quartzofeldspathic, and garnet gneisses. They are strongly peraluminous, with low Yb_N, Rb/Sr, K_2O/Na_2O, and enriched in large ion lithophile elements (LILE). The gneisses within the Ako'ozam-Njabilobe area have a trachy-andesite parentage. The negative anomalies in high field strength elements (HFSE) and enrichments in LILE and light rare earth elements (LREE) suggest a subduction setting for this magmatism. The geochemical signatures including, low K_2O/Na_2O ratio, silica content (67.18 to 73.65 wt%), Yb and Y contents less than 1 and 10 ppm respectively, and low heavy REE values of the studied gneisses are akin to chemical signatures of archean crustal rocks. The $Nb/Th < 1$ and $Th/Yb > 1$ of the studied gneisses indicate that the magma that sourced their protolith is mantle-derived with some degree of crustal contamination. The similarity in whole rock data of the three lithotypes of gneisses within the Ako'ozam-Njabilobe area suggests a possible mechanical mixing during emplacement. The chemistry of the gneisses indicates a possible Archean inheritance during the emplacement of their protoliths, as such could provide insights into the petrogenetic processes controlling crustal growth and aid in understanding the Archean-Proterozoic transition within the Nyong group.

Keywords: Gneiss, Ako'ozam, Njabilobe, Nyong Group, Paleoproterozoic

1. Introduction

The Nyong group, located in southwestern Cameroon, represents a Paleoproterozoic suture zone between the Congo shield and the São Francisco craton. It is comprised of metasedimentary and metaigneous rocks consisting of various gneisses, amphibolites, pyroxenites, eclogites, charnockites, banded iron formations, and granitoids which constitute fragments of greenstone belts, magmatic grey gneisses and intrusive rocks [1, 2]. Gneisses constitute the dominant rock unit and make up the basement of the Nyong group. Greenstone belt rocks (amphibolite, pyroxenites, BIF) within the Nyong group have been at the center of recent works, as these rocks have been associated with iron mineralization [3-7] as well as gold mineralization [8-12]. Equally metasedimentary and metavolcanic rocks have been very useful in geochronologic studies confirming an early-middle Paleoproterozoic age of the Nyong group [2, 7, 13-15]. Despite their contribution to the geochronology of the Nyong group, the chemistry of metavolcanic rocks (gneisses) has been understudied compared to other lithologies (charnockites, metasedimentary and plutonic rocks) within the Nyong group. The geochemical composition of gneisses in the Paleoproterozoic Nyong group is poorly constrained and available data is limited. The origin of the gneisses and their geodynamic evolution is equally not well documented. This paper highlights the results of the petrography and geochemistry of gneisses within the Ako'ozam - Njabilobe area, to determine their geochemical characteristics with emphasis on the geotectonic environment. This will contribute to understanding how the complex history of these rocks has impacted their chemistry and equally add to the geochemical database initiated by previous workers.

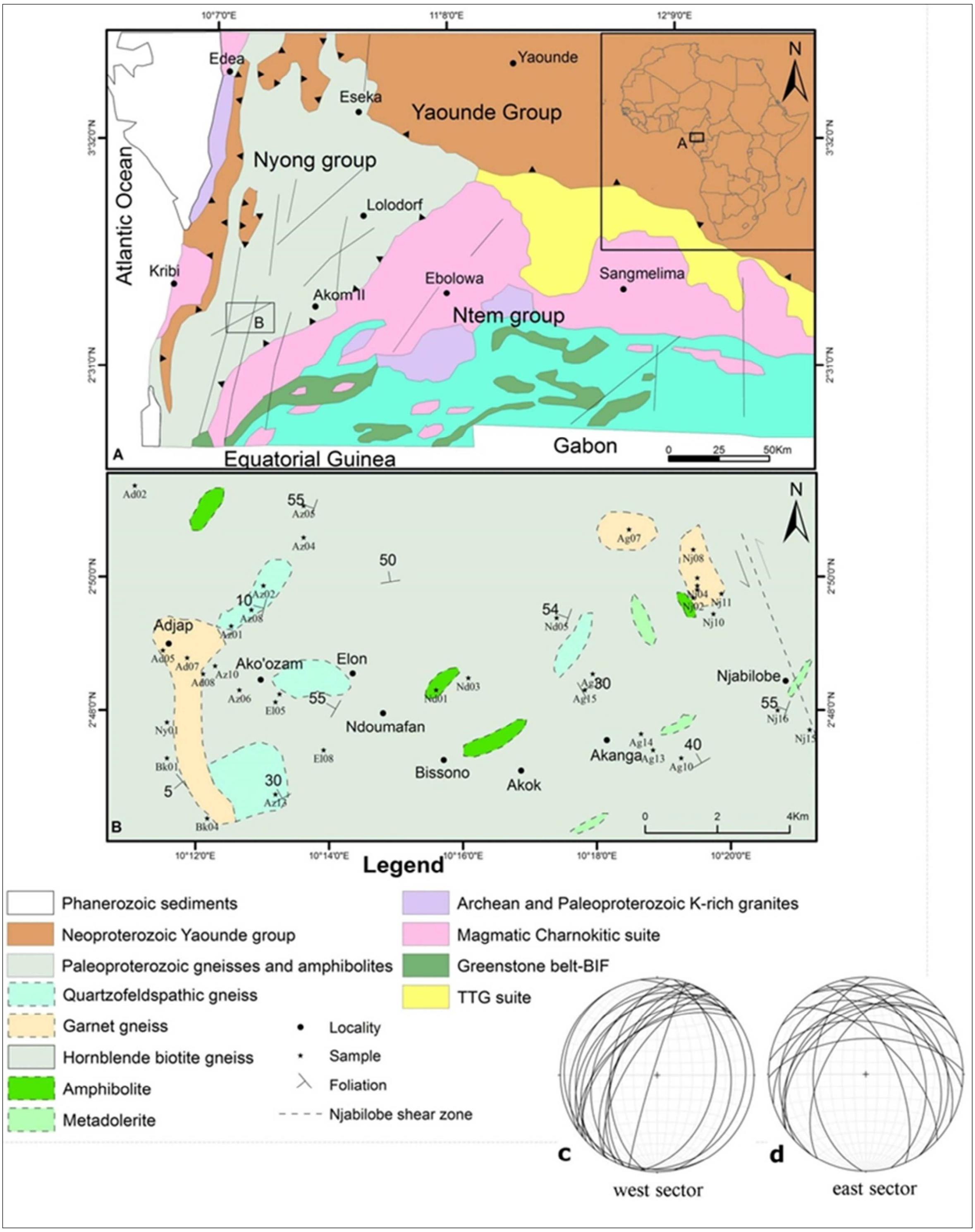

Figure 1. *Simplified geologic map of Southwestern Cameroon (a) modified after Soh Tamehe, L. [22], the geological sketch map of the Ako'ozam-Njabilobe area (b) with sample locations. Orientation diagrams displaying the* $S_{1/2}$ *foliation in the west (c) and east (d) sectors of the study area.*

2. Geological Setting

2.1. Regional Geology

The Precambrian basement in southern Cameroon is comprised of the Archean congo shield (Ntem group), Paleoproterozoic Nyong group, and the Neoproterozoic Yaounde group (Figure 1a). The Paleoproterozoic Nyong group located in southwestern Cameroon represents parts of the archean congo shield reworked during the Eburnean/Trans-Amazonian Orogeny by the collision of the Congo and Sao Francisco shields [2, 13, 14]. It is comprised of meta-sedimentary and metaigneous rocks consisting of gneisses, banded iron formations, amphibolites, pyroxenites, and intrusive rocks such as charnockites, granitoids, metadiorite, TTG suites, syenite, and metadolerites [1, 2]. Greenstone eclogite facies metamorphic rocks equally outcrop within the high-grade Nyong gneisses. These include garnet-clinopyroxenites, garnet-clinopyroxene bearing amphibolites, and serpentinized peridotites [16-18], with SHRIMP U-Pb analyses constraining the metamorphic age of these eclogite rocks at 2.09 Ga [16]. New U-Pb zircon ages infer the deposition age of metasedimentary rocks of the Nyong group to be early-middle Paleoproterozoic [13, 14], with the Pan-African high-grade recrystallization overprinting the granulite-amphibolite metamorphic assemblage of the Nyong group [2, 14, 15, 19]. Structurally, the Nyong group underwent a polycyclic metamorphic evolution typified by a regional S_1/S_2 foliation with low to moderate dip, associated with a variably oriented stretching lineation and local large open folds more or less associated with broadly N–S sinistral strike-slip shear zones [1, 2, 19, 20].

2.2. Local Geology

The Ako'ozam–Njabilobe area is characterized by gneisses hosting amphibolites, and metadolerites as enclaves (Figure 1b). The tectonic evolution of the area is polycyclic, with four deformation phases observed (D_1, D_2, D_3, and D_4) on the field. D_1 corresponds to an early compression in ductile conditions and is observed only as relict structures. D_2 also corresponds to a compression associated with S_2 foliation. D_3 corresponds to a strike-slip deformation associated with C_3 shear zones. D_4 corresponds to a late brittle tectonic phase associated with fractures. Rocks within the area are heterogeneously affected by deformation. To the west of the area around Adjap and Ako'ozam, gneisses display a penetrative foliation ($S_{1/2}$) trending mostly NE-SW with low moderate dips (Figure 1c). In contrast in the eastern part around Njabilobe (Figure 1d), two foliation trends are observed. A dominant NE-SW trend and a less conspicuous NW-SE trend, both with low to moderate dips (5°-65°). The early formed $S_{1/2}$ foliation is overprinted by shallowly to moderate dipping shear zones associated with C_3 mylonitic foliation. At the outcrop scale around Njabilobe, the penetrative foliation ($S_{1/2}$) is crosscut by shallowly to moderately dipping (3°-55°) shear zones. Shear criteria such as recumbent folds overprint the early $S_{1/2}$ banding and are more conspicuous around Akok, Akanga, and Njabilobe. Fractures and joints observed in both sectors of the field are related to late brittle tectonics (D_4), with N-S, NW-SE, and NE-SW orientations.

3. Sampling and Analytical Methods

Systematic mapping and sampling were completed in the study area and thirty-seven (37) fresh and representative samples of gneisses were collected from the Ako'ozam-Njabilobe area. Thin sections were prepared at the Department of Geology, Obafemi Awolowo University, Ile-Ife (Nigeria), and the petrographic observations were carried out at the Institute for Geological and Mining Research, Yaounde, Cameroon. Whole Rock geochemical analysis was conducted at Bureau Veritas Minerals (BVM) Pty Ltd, Canada using Inductively Coupled Plasma-Mass Spectrometry method, with a lithium metaborate fusion digestion technique. Before analysis, the rock powders were pulverized to 85% passing 200 mesh. A 60-element analytical suite was selected comprising of major, trace, and rare earth elements including Total Carbon and Sulphur, with Loss on Ignition and Sum of Oxides calculated. Inductively Coupled Plasma Emission Spectrometry (ICP-ES) was used for major elements while Mass spectrometry (ICP-MS) was employed for trace elements. During analyses, STD SO-19 standards were used and the accuracy of major oxide and trace element analyses were 0.002-0.04% and 0.01-0.5ppm respectively. The discriminant function (DF) was defined as DF= 10.44 - 0.21 SiO_2 - 0.32 Fe_2O_3 (Total Fe) - 0.98 MgO + 0.55 CaO + 1.46 Na_2O + 0.54 K_2O [21].

4. Results

4.1. Petrography

Field and petrographic investigation of gneisses in the Ako'ozam-Njabilobe area indicate that they are comprised of three litho-types which include hornblende-biotite gneiss, quartzo-feldspathic gneiss, and garnet gneiss (Figure 2).

4.1.1. Hornblende-Biotite Gneiss

Hornblende-biotite gneisses are banded coarse-grained porphyroblastic rocks. The banding of mafic and felsic minerals is visible in the hand specimen (Figure 2a), and foliation is distinct on outcrops. In the thin section, the hornblende-biotite gneisses have a heterogranular granoblastic texture (Figure 2b). Two generations of quartz crystals can be distinguished, that is, randomly oriented euhedral-anhedral sutured grains with undulatory extinction and recrystallized subhedral-anhedral (micro-grains) filling micro-fractures within grains and interstitial spaces between the grains (e.g plagioclase). Biotite and hornblende occur as subhedral to euhedral elongated crystals and are preferentially oriented in the gneisses. Alternating domains of plagioclase characterized by bird-eye extinction and sericite-quartz-rich domains, define another foliation in these rocks. Quartz within this domain is dominantly recrystallized. Plagioclase is also albitized with few micro-grains occurring as inclusions in quartz, with oxides generally occurring as small blebs and usually forming rims around hornblende, biotite, and muscovite crystals. Some plagioclase crystals show evidence of deformation such as myrmekitic intergrowth textures.

4.1.2. Quartzo-Feldspathic Gneiss

Quartzo-feldspathic gneisses are moderately mesocratic to leucocratic (Figure 2c). They are coarse-grained porphyroblastic rocks that are weakly foliated. The leucocratic gneisses have a heterogranular granoblastic texture. Quartz crystals range from 0.1 to >5 mm and contain inclusions of plagioclase in certain portions. Quartz crystals show a range of forms from subhedral to anhedral. Microcline and plagioclase feldspar are abundant in these rocks and are generally bounded by quartz crystals (Figure 2d). Muscovite and feldspars crystals make up over 50 % of the groundmass with some phenocryst of quartz embedded in the groundmass. In some parts, plagioclase is often altered to sericite. Platy biotite interlocks with quartz. Oxide phases in these rocks have anhedral and euhedral forms.

4.1.3. Garnet Gneiss

Two types of garnet gneisses were identified in the field. They include coarse and fine-grained garnet gneisses. The former was more prevalent on the field. Garnet gneisses are massive and weakly foliated (Figure 2e), exhibiting a granoblastic heterogranular texture. Their mineral composition includes garnet, quartz, plagioclase, biotite, hornblende, microcline, pyroxene, and oxides, (Figure 2f). Hornblende contains inclusions of quartz. Porphyroblasts of garnet often contain inclusions of quartz, hornblende, and oxides.

Figure 2. *Representative rock samples and corresponding photomicrographs of hornblende-biotite gneiss (a, b), quartzo-feldspathic gneiss (c, d), and garnet gneiss (e, f) within the Ako'ozam-Njabilobe area. Qtz: quartz, Ms: muscovite, Hb: hornblende, Pl: plagioclase, Gt: garnet, Ox: oxide.*

4.2. Whole-Rock Geochemistry

Thirty-seven representative samples of hornblende-biotite, quartzo-feldspathic, and garnet gneisses were selected for whole-rock geochemistry. The summarized data is presented in table 1. The entire dataset is available in the supplementary data.

***Table 1.** Summary of the major (wt %) and trace element (ppm) compositions of gneisses in the Ako'ozam-Njabilobe area, HBG: hornblende-biotite gneiss, QFG: quartzo-feldspathic gneiss, GG: garnet gneiss.*

	HBG (n=17)		QFG (n=10)		GG (n=10)	
	Average	SD	Average	SD	Average	SD
Wt%						
SiO_2	70.3	1.2	70.6	3.9	69.5	1.7
Al_2O_3	15.2	0.6	14.8	2.0	15.2	0.7
Fe_2O_3	1.8	0.1	2.0	0.2	2.3	0.5
MgO	0.5	0.1	0.6	0.1	0.6	0.2
CaO	1.8	0.2	1.9	0.3	2.0	0.4
Na_2O	4.5	0.3	4.5	0.7	4.5	0.3
K_2O	4.1	0.1	4.0	0.6	4.0	0.2
TiO_2	0.3	0.0	0.3	0.1	0.3	0.1
P_2O_5	0.1	0.0	0.2	0.0	0.1	0.0
LOI	1.1	0.2	1.0	0.3	1.2	0.2
Sum	99.9	0.0	99.9	0.0	99.9	0.0
Mg #	36.2	3.2	35.3	4.4	35.2	4.3
DF	4.6	1.3	4.2	2.1	4.3	0.8
ppm						
Ba	881.9	43.6	877.2	124.2	886.5	58.4
Cs	6.8	2.5	6.6	1.6	6.2	1.5
Rb	168.1	93.7	137.3	22.1	147.4	47.3
Sr	719.3	57.3	733.0	109.6	742.8	65.6
Ga	16.4	1.1	17.3	3.1	16.7	1.5
Hf	3.8	0.4	4.0	0.6	3.8	0.3
Nb	5.7	0.9	5.9	1.3	5.7	0.8
Sn	2.1	0.3	1.7	0.5	1.9	0.3
Ta	0.7	0.2	0.6	0.1	0.6	0.1
Th	15.3	2.7	16.3	3.1	14.5	3.0
U	7.1	1.1	7.4	1.8	6.9	1.5
V	24.8	3.4	26.6	5.8	32.9	11.6
Zr	122.9	13.1	127.0	15.1	121.3	9.7
Y	5.6	1.2	5.6	1.0	5.9	1.2
Mo	0.8	0.6	1.1	0.4	1.6	0.9
Cu	11.2	1.9	11.3	2.0	16.3	8.2
Pb	5.5	0.7	5.6	1.1	7.5	2.6
Zn	47.1	8.9	51.1	13.1	52.9	13.0
Ni	6.8	1.1	7.8	1.5	8.3	2.4
Co	2.7	0.5	3.1	0.8	4.3	1.8
Sc	2.3	0.5	2.3	0.7	3.0	1.2
Be	3.9	1.1	5.1	1.4	3.7	1.7
As	0.7	0.1	0.8	0.2	0.8	0.1
Sb	0.1	0.1	0.2	0.1	0.2	0.1
Bi	0.2	0.1	0.2	0.0	0.2	0.2
Au (*ppb*)	2.5	2.2	1.2	0.8	1.6	1.4
Tl	0.4	0.1	0.4	0.1	0.4	0.1
La	27.8	4.3	28.2	4.5	26.4	4.2
Ce	54.0	8.4	55.5	8.8	51.6	8.2
Pr	5.9	0.9	6.1	1.1	5.7	0.9
Nd	21.0	3.0	22.1	4.1	20.3	3.4
Sm	3.4	0.6	3.6	0.7	3.4	0.5
Eu	0.7	0.1	0.7	0.1	0.7	0.1
Gd	2.2	0.3	2.4	0.4	2.2	0.3
Tb	0.3	0.0	0.3	0.1	0.3	0.0
Dy	1.2	0.2	1.2	0.2	1.2	0.2
Ho	0.2	0.0	0.2	0.0	0.2	0.1
Er	0.5	0.2	0.5	0.1	0.6	0.1
Tm	0.1	0.0	0.1	0.0	0.1	0.0
Yb	0.5	0.1	0.5	0.1	0.5	0.1
Lu	0.1	0.0	0.1	0.0	0.1	0.0
La_N/Yb_N	39.1	5.8	41.7	3.0	35.7	8.2
Gd_N/Yb_N	3.7	0.6	4.2	0.3	3.6	0.7
Ce/Ce*	1.0	0.0	1.0	0.0	1.0	0.0
Eu/Eu*	0.8	0.1	0.8	0.0	0.8	0.0

4.2.1. Major Element Geochemistry

Gneisses in the Ako'ozam-Njabilobe area are acidic in composition with SiO_2 content ranging from 67.18 to 73.65 wt%. Al_2O_3 contents are high ranging between 13.37 to 16.08 wt% except for sample EL05 which is 9.11 wt%. The non-variability of alumina suggests a calc-alkaline affinity (Figure 3). The Fe_2O_3+MgO+MnO+TiO_2 sum varies from 2.19 wt% to 5.24 wt%. NaO_2 is slightly higher than K_2O in all samples except for Nj03, El04, and Nj16. The total alkali content ranges from 5.15 to 9.29 wt%. The gneisses are calc-alkalic and have a higher molar A/CNK ratio indicating their peraluminous nature. Major elements have a negative correlation with SiO_2 in hornblende-biotite gneisses, similar to those of quartzo-feldspathic gneiss, while major elements in garnet gneiss have a negative correlation with SiO_2 except K_2O (Figure 4).

4.2.2. Trace and REE Element Geochemistry

Large ion lithophile elements (LILE) contents in the gneisses are high except for Cs which is low. Ba ranges between 770 to 977 ppm except for sample El05 which is 541 ppm. Rb shows high and relatively constant values ranging from 120.5 to 162.8 ppm, except samples El04 and Nj16 which are extremely high reaching 410.7 ppm and 421.6 ppm respectively. Sr values are high (725.8-817.1 ppm) except in sample El05 which is 426.8 ppm. Cs values range from 3.4 to 9.3 ppm except for samples El04 and Nj16 which are 13.1 and 13.2 ppm respectively. High field strength elements (HFSE) such as Hf and Nb contents are low in all samples, ranging from 2.9 to 4.7 ppm and 4.6 to 8 ppm respectively. Ta is depleted with extremely low values (<1 ppm). Zr has elevated contents varying from 104.4 to 145.7 ppm except in sample Nj16 which is slightly lower (99.5 ppm). Base metals have averagely low values, with Zn ranging from 26 to 72 ppm, Pb from 4 to 12.6 ppm, and Cu ranging from 9.6 to 16.8ppm except in samples Ny01 and Ad02, with Cu values of 21.7ppm and 37.3ppm respectively. All samples are depleted in Sn with uniform values ranging from 1 to 3 ppm. Au values in some samples are higher than the crustal abundance. It ranges between 0.6 to 3.3 ppb except for samples El04, Nj15, and Nj03 with 6.7, 5.7, and 5.2 ppb respectively.

Harker's diagram indicates that trace elements have a negative correlation with silica except for Cs which is positive for hornblende-biotite and garnet gneisses and Rb which is positive for hornblende-biotite gneisses (Figure 5). Plagioclase fractionation possibly accounts for the decrease in Sr and Ba and the slight increase in Rb with increasing silica. The studied gneisses display enrichment in light rare earth elements (LREE~89.97 - 144.74) and depletion in heavy rare earth elements (HREE~3.72 - 6.85). The chondrite-normalized REE patterns of the studied gneisses show LREE enrichment (La_N/Yb_N = 19.9 - 45.5) relative to HREE (Gd_N/Yb_N = 2.09 - 5.44) with a negative Eu anomaly (Eu/Eu* = 0.73 – 0.84), indicating plagioclase removal by fractional crystallization (Figure 6).

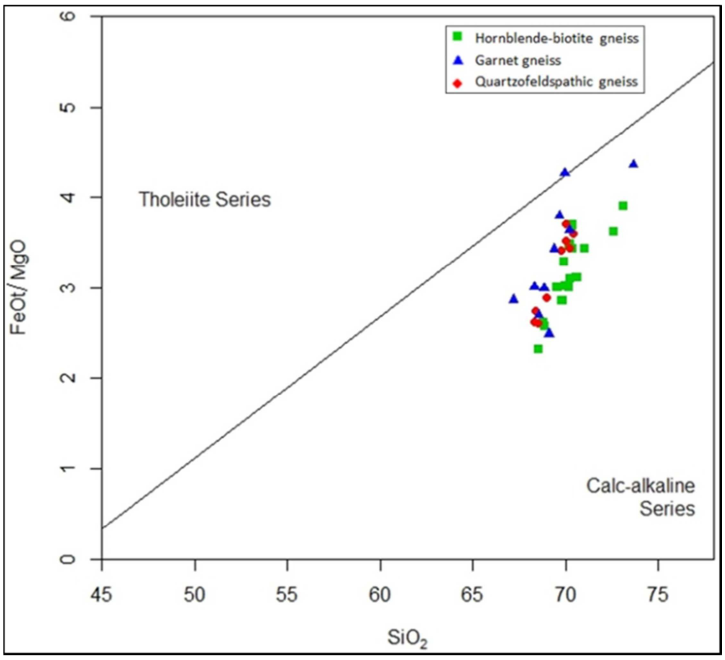

Figure 3. *Calc-alkaline nature of the gneisses in the Ako'ozam-Njabilobe area [23].*

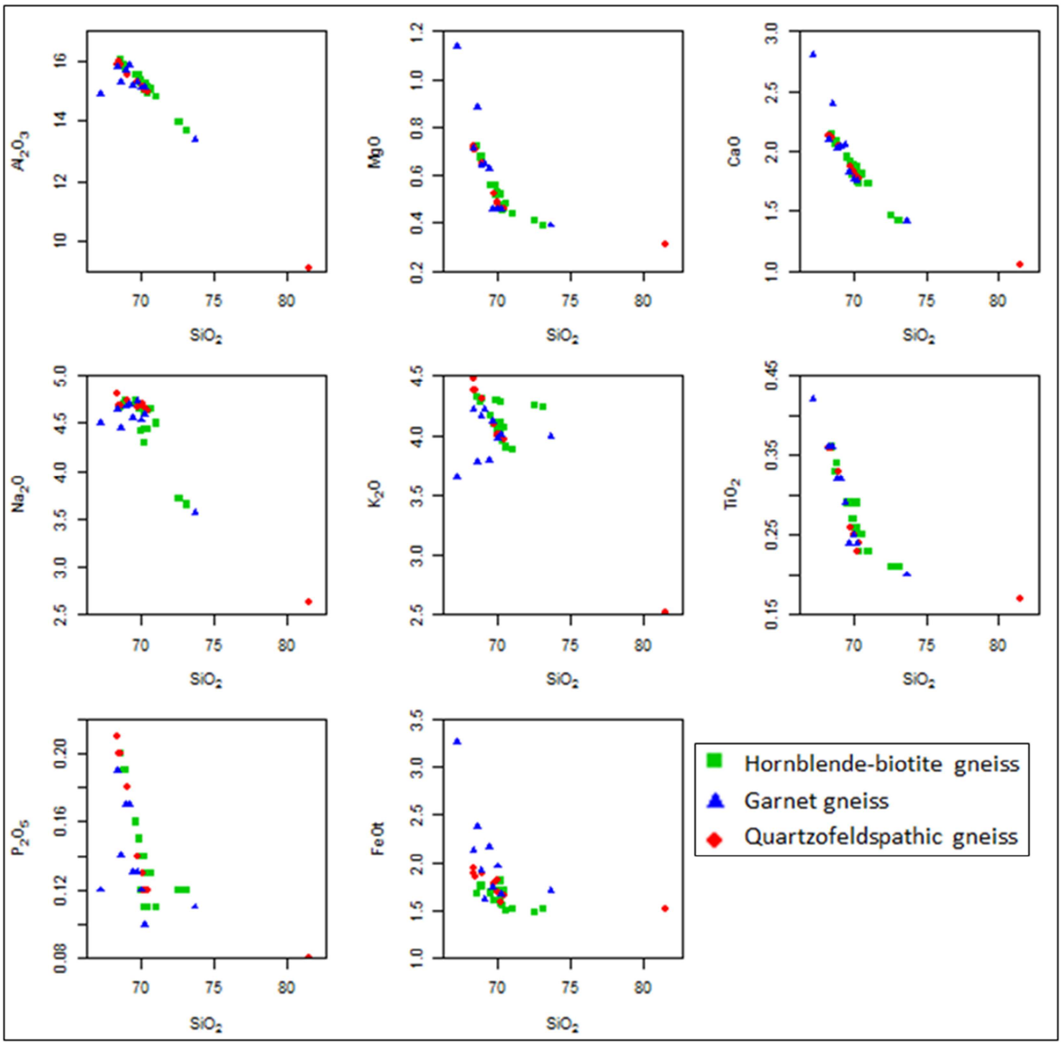

Figure 4. *Harker's variation diagram of major oxides in gneisses of the Ako'ozam-Njabilobe area.*

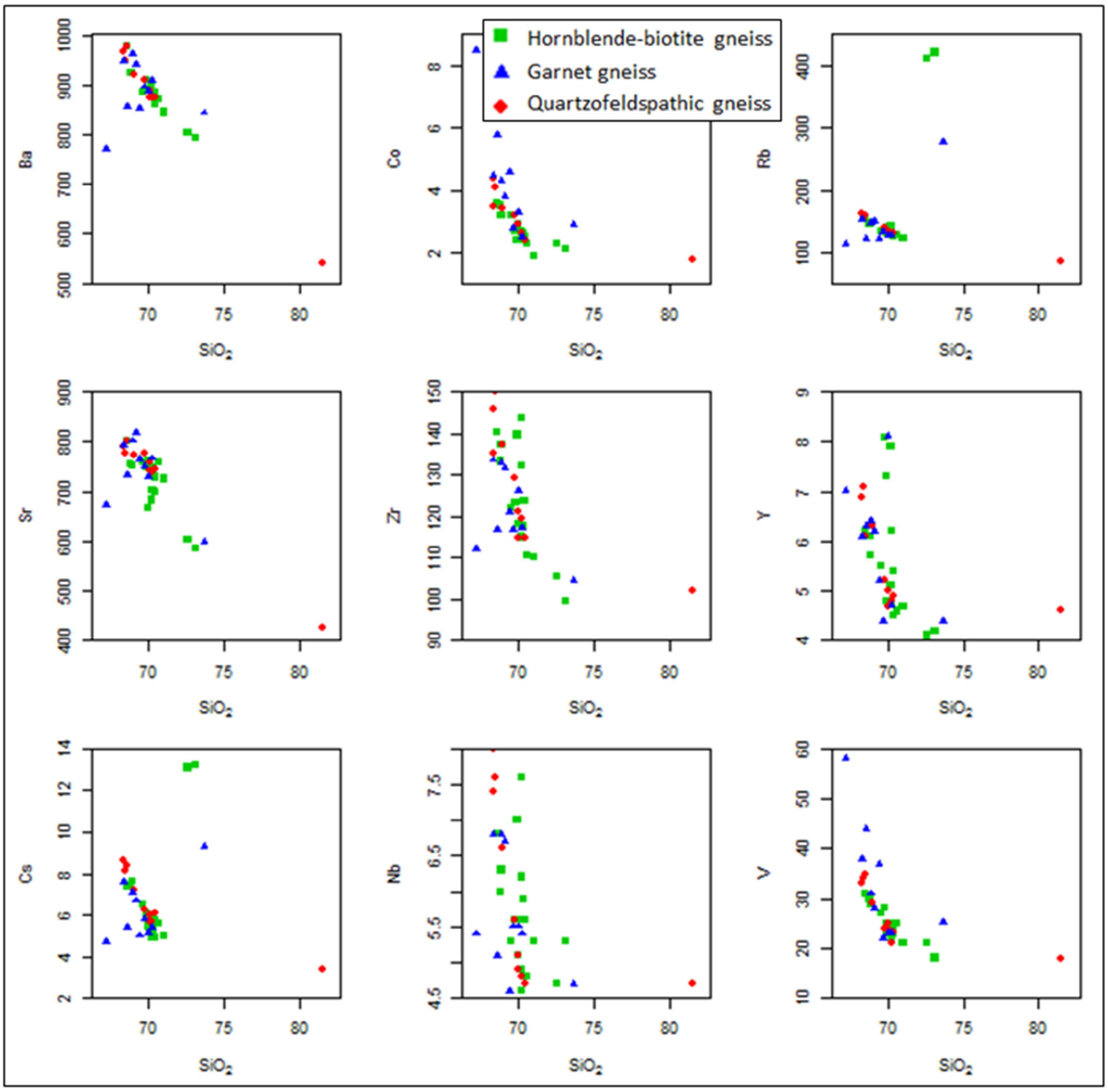

Figure 5. *Harker's variation diagram of some trace elements in gneisses of the Ako'ozam-Njabilobe area.*

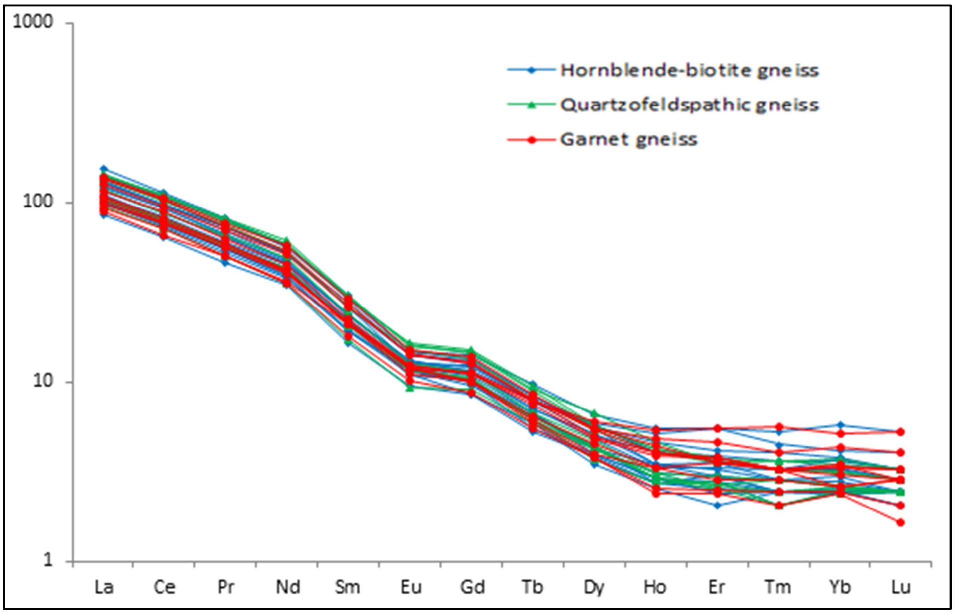

Figure 6. *Chondrite [24] normalized REE plot of gneisses in the Ako'ozam-Njabilobe area.*

5. Discussion

5.1. Element Mobility

The elevated concentrations of LILE relative to HFSE in the studied gneisses are a general feature recognized in arc magmas [25]. The LILE enrichment in arc magmas is regarded as a result of the deposition of these elements by HFSE-poor fluids ascending from the subducted crust [26]. The elements Rb, Sr, Sm, Nd, U, and Pb are generally redistributed during the movement of fluids associated with regional metamorphism. On the diagrams of Zr versus Nb, Nd, Sm, Ti, Y, and HREE, the samples display systematic strong correlations with Zr (Figure 7), indicating the low mobility of these elements. Contrary to HFSE and HREE, Rb, K, Na, and Sr, have scattered trends with Zr abundances (Figure 7) and display significant enrichments and depletions on the primitive mantle-normalized diagrams (Figure 10). This is an indication that they are relatively more mobile [27, 28]. The Ngovayang orthogneisses show impoverishment in LILE [29], contrary to the studied gneisses. Ndong, F. B., et al. attributed this LILE impoverishment to be a consequence of dehydration reactions that occur during the passing from the amphibolite to the granulite facies [29]. The observed difference in orthogneisses in the Ngovayang area and those presented in this study could be an indication that the gneisses which make up the basement of the Nyong group fall within the transition between amphibolite and granulite facies metamorphism [30]. The loss on ignition of these acidic formations is slightly higher than 1% except for a few samples where it is lower than 1%. This indicates that the alteration phenomena of some minerals as noted in the petrography such as the sericitization of quartz and albitization of feldspars are reduced [28].

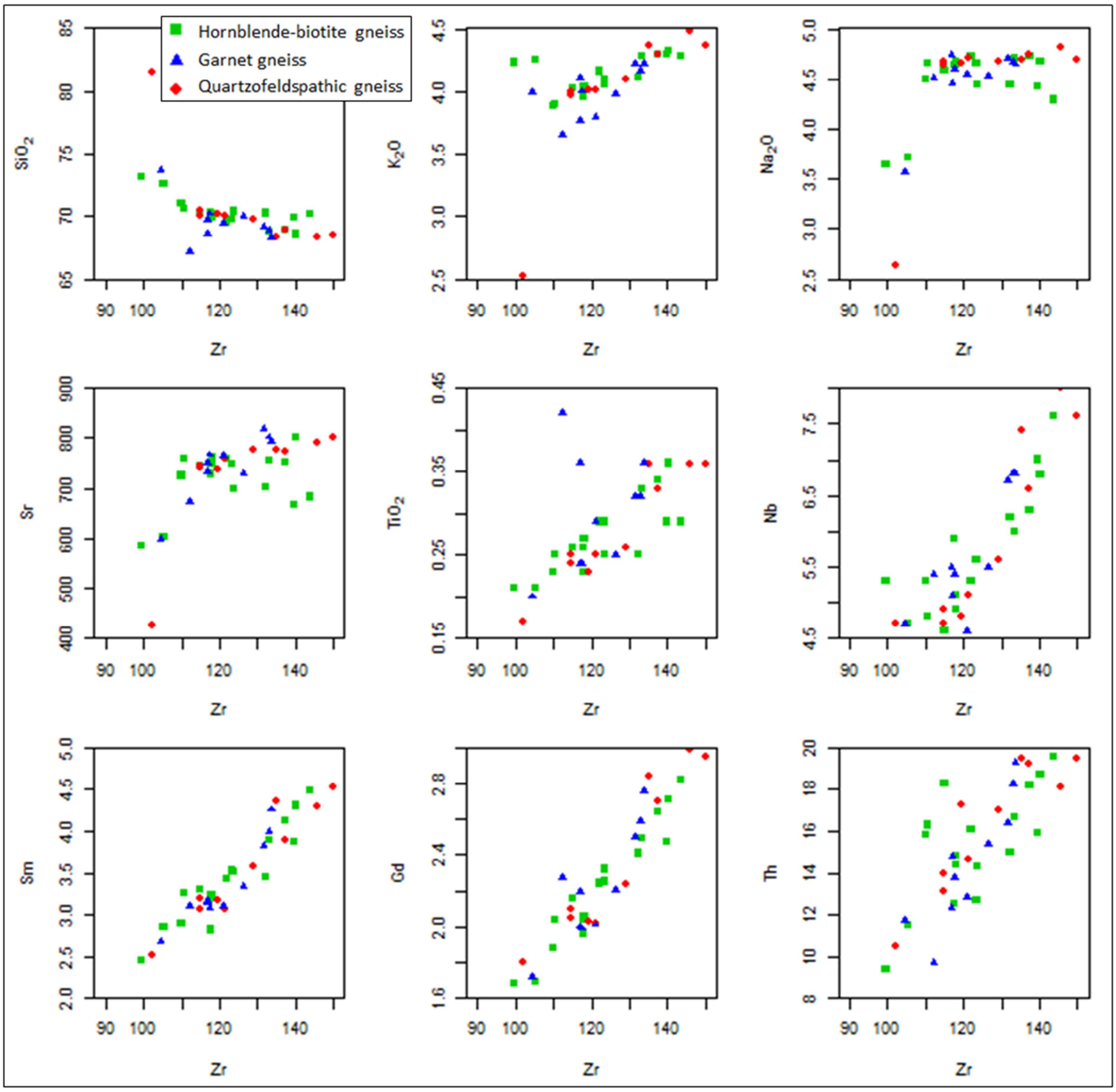

Figure 7. *Zr vs. selected element variation diagrams to highlight the limited effects of alteration or mobility.*

5.2. Protolith

The protolith of gneisses can be determined using a discriminant function (DF) as long as the MgO<6% and SiO2<90% [21], with positive DF values suggesting an igneous origin while negative DF values point to a sedimentary source. DF is positive for all samples (Table 1), indicating an igneous protolith of the studied gneisses. To determine the original igneous rock from which the studied gneisses were derived, less mobile elements such as Nb, Zr, Hf, and Y, were used because these elements are hardly affected by post-magmatic processes such as metamorphism and thus will represent the initial parent material. On the Nb/Y - Zr/Ti diagram (Figure 8), all samples plot within the trachy-andesite field except two samples that fall within the trachyte field.

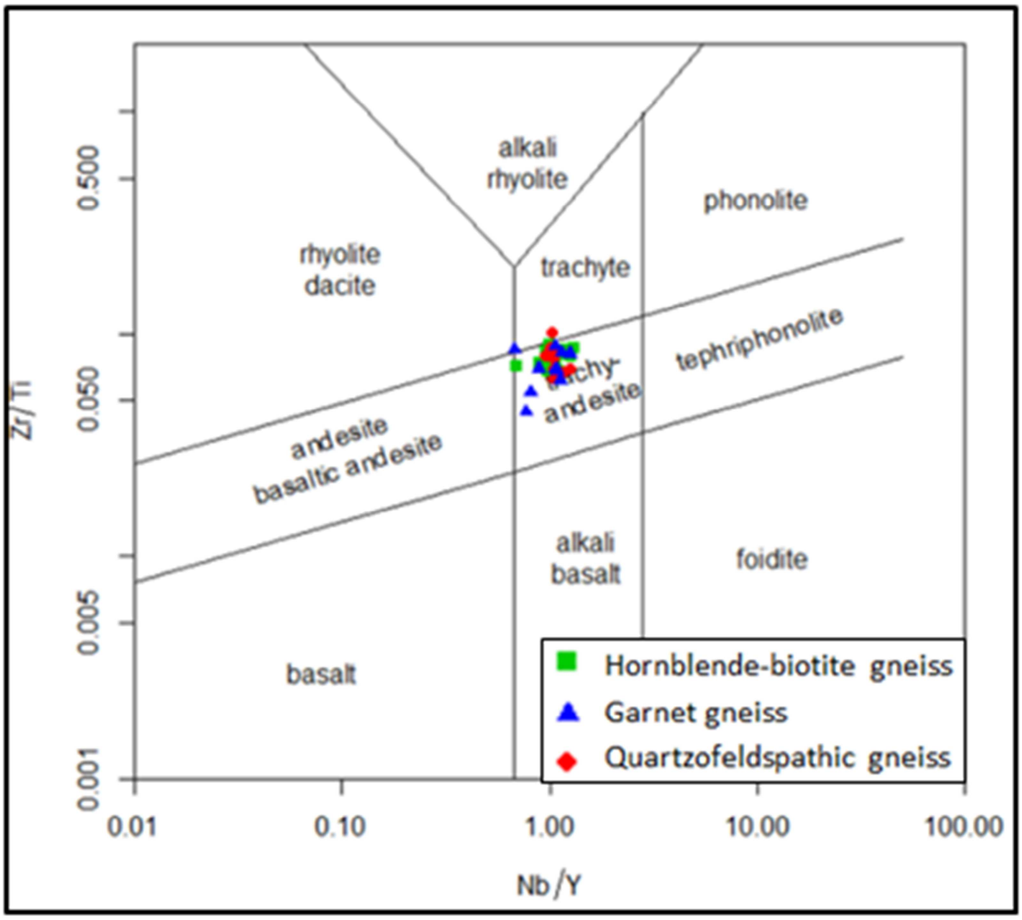

Figure 8. *Nb/Y - Zr/Ti plot (modified by Pearce, J. A. [31]) of gneisses in the Ako'ozam-Njabilobe area.*

5.3. Tectonic Setting

To constrain the tectonic setting under which the igneous protolith of the studied gneisses was emplaced, a trace element discrimination diagram was employed. The data plot (Figure 9) indicates a major emplacement within a volcanic arc regime with few samples plotting in the syn-collision regime. This is akin to data from garnet and amphibole-rich gneiss in Eseka [32], pyroxene gneisses in Kelle Bidjoka [5]. More recent data confirms the arc setting for the Nyong group crustal rocks associated with the Eburnean/Trans-Amazonian orogeny in Cameroon [33].

5.4. Geodynamic Implications

Primitive mantle [24] normalized trace elements of the studied Nyong gneisses (Figure 10) show enrichment of LILE and LREE elements, negative anomalies of Nb, Ta, Zr, and Pr, a slightly positive Sr anomaly, which is typical of subduction-related settings [34-36]. Nédélec, A., et al. reported positive Na_2O/K_2O ratio in Eseka gneisses and that such ratios, coupled with the range in silica content (67.18 to 73.65 wt%) and trace element values are similar to those of Archean TTG [37-39]. According to Ganwa, A. A., et al. the characteristic chemical signatures of the Archean crust include extremely low content in Y and heavy REE [40]. As such, TTGs will usually display Yb and Y contents less than 1 and 10 ppm respectively. Typical calc-alkaline rocks have Yb and Y contents which are two to three times higher than TTGs.

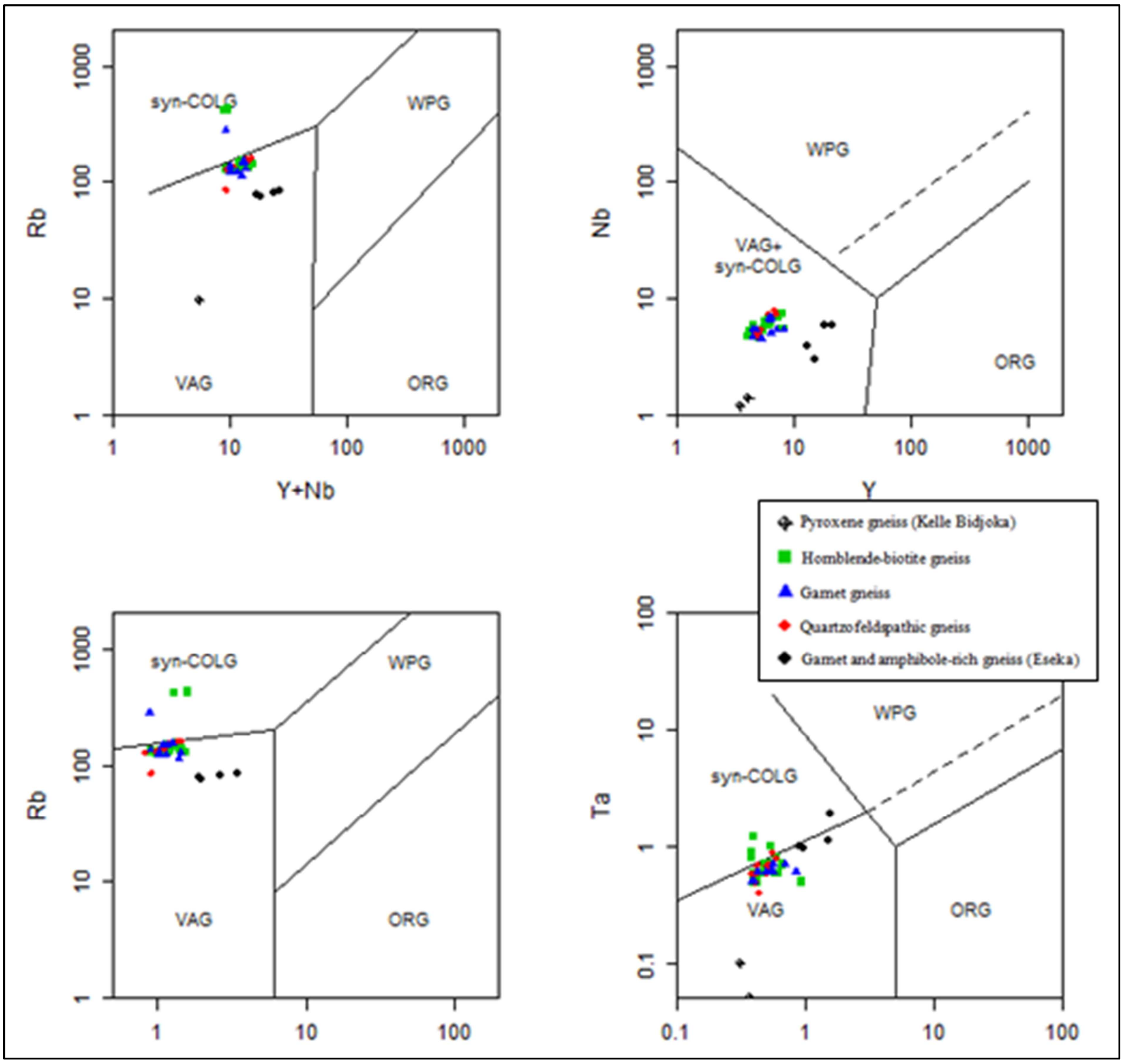

Figure 9. *Tectonic setting discrimination diagram after Pearce, J. A. [41] of gneisses in the Ako'ozam-Njabilobe area.*

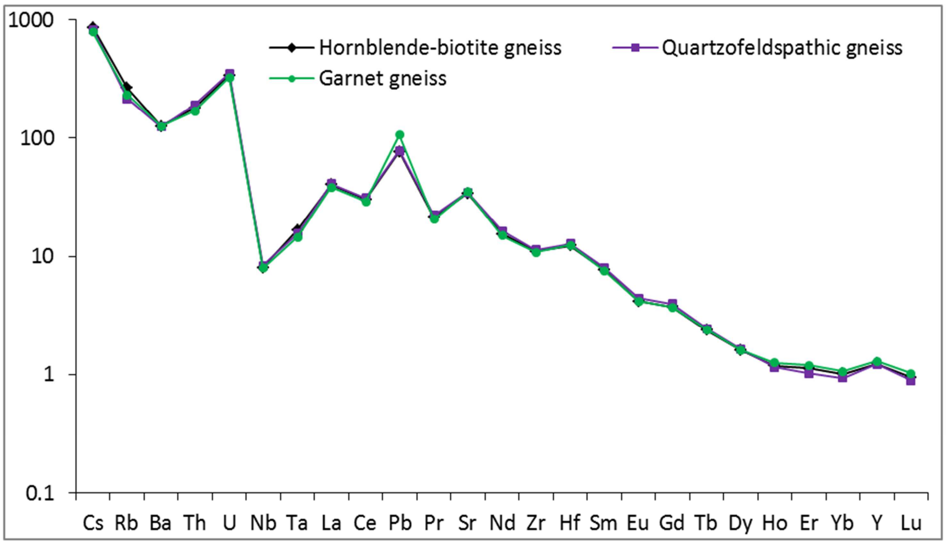

Figure 10. *Primitive mantle [24] normalized average of Nyong gneisses for incompatible elements.*

Table 2. *Selected average element ratios of the Ako'ozam-Njabilobe orthogneisses compared with Archean granitoids and Paleoproterozoic orthogneisses of the Caico complex.*

	Archean		Average Caico complex orthogneisses[3]				Averages of studied gneisses[4]		
	TTG[1]	**CARG[2]**	**BIR**	**TON**	**AG**	**GR**	**HBG**	**QFG**	**GG**
SiO_2 (Wt.%)	64.9-74.7	69.5-72.3	48.4-62.0	60.3-79.2	57.3-77.0	62.1-77.9	68.5-73.1	68.4-81.5	67.2-73.6
K_2O/Na_2O	0.4	0.9	0.7	0.6	1.2	1.5	0.9	0.9	0.9
Mg number	43.0	34.0	50.0	40.0	38.0	26.0	36.2	35.3	35.2
Rb/Sr	0.1	0.3	0.1	0.2	0.3	0.8	0.2	0.2	0.2
A/CNK	1.0	1.0	0.8	1.0	1.0	1.0	1.5	1.4	1.5
$(La/Yb)_N$	41.7	39.3	11.1	27.3	29.1	33.3	39.1	41.7	35.7
Yb_N	1.5-5	3.0-9.1	11.1	9.4	13.1	11.7	3.1	2.9	3.3
Eu/Eu*	1.3	0.7	1.0	0.9	0.9	0.4	0.8	0.8	0.8
Zr/Sc	32.3	3.3	8.7	20	32.1	38.2	54.7	41.7	45.3

[1][42], [2][43], [3][44], [4]data from supplementary file. BIR, basic to intermediate rocks; TON, tonalitic gneiss; AG, augen gneiss; GR, granitic gneiss; HBG, hornblende-biotite gneiss; QFG, quartzo-feldspathic gneiss; GG, garnet gneiss.

The authors attribute these low values to the partial fusion of a source containing garnet as a residual phase. Gneisses in the Ako'ozam-Njabilobe area have Yb and Y values less than 1 and 10 respectively, with Sr/Y ratios far greater than 30 and low HREE. The chemistry suggests an archean inheritance during the emplacement of their protoliths, such as those of Paleoproterozoic orthogneisses in the Meiganga area [40] and gneisses from Edea and Eseka [32]. The negative sub-vertical trends of Co, Sr, V, Nb, and Ba with increasing silica (Figure 6) is an indication that fractional crystallization is the major mechanism of differentiation. Similar trends were observed in Paleoproterozoic orthogneisses (Caico complex), NE Brazil [44]. Contrary to the Caico gneisses, which have higher Yb_N, Rb/Sr, K_2O/Na_2O, and lower A/CNK, $(La/Yb)_N$ and Zr/Sc (Table 2), gneisses of the Ako'ozam-Njabilobe area have lower Yb_N, Rb/Sr, K_2O/Na_2O and higher A/CNK, $(La/Yb)_N$ and Zr/Sc, akin to late Archean calc-alkaline granites [43]. The Nb/Th < 1 and Th/Yb >1 of the studied gneisses indicate that the magma that sourced their protolith is mantle-derived with some degree of crustal contamination [45].

6. Conclusions

The Ako'ozam-Njabilobe area is located in the Eburnean belt, which covers Central Africa and extends to northeastern Brazil. The geochemical composition of gneisses within this area was studied to ascertain their tectonic setting and geodynamic evolution within the Nyong group. Three lithotypes of gneisses were identified within the Ako'ozam-Njabilobe area. These include hornblende-biotite, quartzo-feldspathic and garnet gneisses. The mineral assemblages of the studied gneisses suggest an upper amphibolite facies metamorphism. They are sourced from trachy-andesites. The studied rocks are peraluminous, high-Na, LILE, and LREE-enriched sourced from deep-seated calc-alkaline magmas emplaced in a subduction-like tectonic setting. The magma that sourced the protolith of the gneisses is mantle-derived with some degree of crustal contamination. The similarity in the major, trace, and REE chemistry of these meta-volcanic rocks suggests a possible mechanical mixing during emplacement. A further isotopic and geochronologic study of the rocks is recommended to provide more clarity on the similarity in whole rock chemistry and their petrogenesis.

Acknowledgements

The data presented here is part of the Ph.D. thesis of the first author at the Pan African University Life and Earth Sciences Institute (PAULESI). It is funded by the African Union Commission through the Pan African University.

References

[1] Penaye, J., Toteu, S. F., Tchameni, R., Van Schmus, W. R., Tchakounté, J., Ganwa, A., Minyem, D., Nsifa, E. N. (2004). The 2.1 Ga West central African belt in Cameroon: extension and evolution. J. Afri. Earth Sci. 39, 159-164.

[2] Lerouge, C., Cocherie, A., Toteu, S. F., Penaye, J., Milési, J. P., Tchameni, R., Deloule, E. (2006). Shrimp U–Pb zircon age evidence for Paleoproterozoic sedimentation and 2.05 Ga syntectonic plutonism in the Nyong Group, South-Western Cameroon: consequences for the Eburnean–Transamazonian belt of NE Brazil and Central Africa. J. Afri. Earth Sci. 44, 413-427.

[3] Moudioh, C., Tamehe, L. S., Ganno, S., Tankwa, M. N., Soares, M. B., Ghosh, R., Nzenti, J. P. (2020). Tectonic setting of the Bipindi greenstone belt, northwest Congo craton, Cameroon: implications on BIF deposition. Journal of African Earth Sciences, 171, 103971.

[4] Kwamou, W. M., Djibril, K. N. G., Guimollaire, N. D., & Patrick, A. K. (2021). Petrogenesis and U–Pb zircon dating of amphibolite in the Mewengo iron deposit, Nyong series, Cameroon: fingerprints of iron depositional geotectonic setting. Arabian Journal of Geosciences, 14 (10), 1-15.

[5] Nzepang Tankwa, M., Ganno, S., Okunlola, O. A., Tanko Njiosseu, E. L., Soh Tamehe, L., Kamguia Woguia, B., & Nzenti, J. P. (2021). Petrogenesis and tectonic setting of the Paleoproterozoic Kelle Bidjoka iron formations, Nyong group greenstone belts, southwestern Cameroon. Constraints from petrology, geochemistry, and LA-ICP-MS zircon U-Pb geochronology. International Geology Review, 63 (14), 1737-1757.

[6] Soh Tamehe, L., Wei, C., Ganno, S., Rosiere, C. A., Nzenti, J. P., Ebotehouna, C. G., & Lu, G. (2021). Depositional age and tectonic environment of the Gouap banded iron formations from the Nyong Group, SW Cameroon: insights from isotopic, geochemical and geochronological studies of drillcore samples. Geoscience Frontiers, 12 (2), 549-572.

[7] Soh Tamehe, L., Wei, C., Ganno, S., Rosière, C. A., Li, H., Soares, M. B.,... & Bekker, A. (2022). Provenance of metasiliciclastic rocks at the northwestern margin of the East Gabonian Block: Implications for deposition of BIFs and crustal evolution in southwestern Cameroon. Precambrian Research, 376, 106677.

[8] Fuanya, C., Yongue Fouateu, R., Kankeu, B. (2014). Geological study of gold indices at Ako'ozam, Akom II region (south Cameroon). Sci. Technol. Dev. 15, 98–106.

[9] Mimba, M. E., Tamnta, N. M., Suh, C. E. (2014). Geochemical dispersion of gold in stream sediments in the Paleoproterozoic Nyong Series, southern Cameroon. Sci. Res. 2 (6), 155–165.

[10] Omang, B. O., Suh, C. E., Lehmann, B., Vishiti, A., Chombong, N. N., Fon, A. N., Egbe, J. A., Shemang, E. M. (2015). Microchemical signature of alluvial gold from two contrasting terrains in Cameroon. J. Afr. Earth Sci. 112, 1–14.

[11] Binam Mandeng, E. P., Bidjeck, L. M. B., Wambo, J. D. T., Taku Jr., A., Betsi, T. B., Ipan, A. S., Nfada, L. T., Dieudonné, L. B. (2018). Lithologic and structural mapping of the Abiete–Toko gold district in southern Cameroon, using Landsat 7 ETM+/SRTM. Compt. Rendus Geosci. 350 (3), 130–140.

[12] Fuanya, C., Bolarinwaa, A. T., Kankeu, B., Yongue, R. F., Ngatcha, R. B., Tangko, E. T. (2019). Morphological and chemical assessment of alluvial gold grains from Ako'ozam and Njabilobe, southwestern Cameroon. J. Afr. Earth Sci. 154, 111–119.

[13] Owona, S., Ratschbacher, L., Ngapna, M. N., Gulzar, A. M., Ondoa, J. M., & Ekodeck, G. E. (2021a). How diverse is the source? Age, provenance, reworking, and overprint of Precambrian meta-sedimentary rocks of West Gondwana, Cameroon, from zircon U-Pb geochronology. Precambrian Research, 359, 106220.

[14] Owona, S., Ratschbacher, L., Afzal M, G., Nsangou Ngapna, M., Mvondo Ondoa, J., & Ekodeck, G. E. (2021b). New U–Pb zircon ages of Nyong Complex meta-plutonites: Implications for the Eburnean/Trans-Amazonian Orogeny in southwestern Cameroon (Central Africa). Geological journal, 56 (4), 1741-1755.

[15] Woguia, B. K., Nono, G. D. K., Tsoungui, P. E. N. E., Njiosseu, E. L. T., Kenne, P. A., & Nzenti, J. P. (2022). Geochemistry and U–Pb zircon age of the Paleoproterozoic metasedimentary rocks from the Bidou I, Nyong Series, Cameroon: Implications for provenance and tectonic setting. Arabian Journal of Geosciences, 15 (2), 1-21.

[16] Loose, D., Schenk, V. (2018). 2.09 Ga old eclogites in the Eburnian-Transamazonian orogen of southern Cameroon: Significance for Palaeoproterozoic plate tectonics. Precambrian Res. 304, 1-11.

[17] Bouyo Houketchang, M., Penaye, J., Mouri, H., Toteu, S. F. (2019). Eclogite facies metabasites from the Paleoproterozoic Nyong Group, SW Cameroon: Mineralogical evidence and implications for a high-pressure metamorphism related to a subduction zone at the NW margin of the Archean Congo craton. J. Afri. Earth Sci. 149, 215-234.

[18] Nga Essomba Tsoungui, P., Ganno, S., Tanko Njiosseu, E. L., Ndema Mbongue, J. L., Kamguia Woguia, B., Soh Tamehe, L., & Nzenti, J. P. (2020). Geochemical constraints on the origin and tectonic setting of the serpentinized peridotites from the Paleoproterozoic Nyong series, Eseka area, SW Cameroon. Acta Geochimica, 39 (3), 404-422.

[19] Toteu, S. F., Van Schmus, W. R., Pénaye, J., Nyobé, J. B. (1994). U/Pb and SM/Nd evidence for Eburnean and Pan-African high-grade metamorphism in cratonic rocks of southern of Cameroon. Precambrian Res. 67, 321-347.

[20] Kankeu, B., Greiling, R. O., Nzenti, J. P., Ganno, S., Danguene, P. Y., Bassahak, J., Hell, J. V. (2018). Contrasting Pan-African structural styles at the NW margin of the Congo Shield in Cameroon. J. Afri. Earth Sci. 146, 28-47.

[21] Shaw, D. M. (1972). The origin of the Apsley Gneiss, Ontario. Can. J. Earth Sci. 9, 18-35.

[22] Soh Tamehe, L., Tankwa, M. N., Chongtao, W., Ganno, S., Ngnotue, T., Nono, G. D. K., Nzenti, J. P. (2018). Geology and geochemical constrains on the origin and depositional setting of the Kpwa–Atog Boga banded iron formations (BIFs), northwestern Congo craton, southern Cameroon. Ore Geol. Rev. 95, 620-638.

[23] Miyashiro, A. (1974). Volcanic rock series in island arcs and active continental margins. Amer. Jour. Sci., 274, 321-355.

[24] Sun, S. S., McDonough, W. S. (1989). Chemical and isotopic systematics of oceanic basalts: implications for mantle composition and processes. Geol. Soc. Lond. Spec. Publ. 42, 313-345.

[25] Ague, J. J. (2017). Element mobility during regional metamorphism in crustal and subduction zone environments with a focus on the rare earth elements (REE). American Mineral 102, 1796-1821.

[26] Becker, H., Jochum, K. P., Carlson, R. W. (2000). Trace element fractionation during dehydration of eclogites from high-pressure terranes and the implications for element fluxes in subduction zones. Chemical Geol. 163, 65-99.

[27] Polat, A., Hofmann, A. W., Rosing, M. T. (2002). Boninite-like volcanic rocks in the 3.7–3.8 Ga Isua greenstone belt, West Greenland: geochemical evidence for intra-oceanic subduction zone processes in the early Earth. Chemical Geol. 184, 231-254.

[28] Polat, A., Hofmann, A. W. (2003). Alteration and geochemical patterns in the 3.7–3.8 Ga Isua greenstone belt, West Greenland. Precambrian Res. 126, 197-218.

[29] Ndong, F. B., Nfada, L., Ntomba, M. S., Atouba, C. L. O., Nzenti, J. P., Ondoa, J. M. (2016). Chemical character of the Ngovayang gneisses in the northwestern border of the Congo craton (south Cameroon): sources and geotectonic framework. International J. Innov. Appl. Stud. 14, 976-996.

[30] Fowler, M. B. (1986). Large-ion lithophile element characteristics of an amphibolite facies to granulite facies transition at Gruinard Bay, North-west Scotland. J. Metamorphic Geol. 4, 345-359.

[31] Pearce, J. A. (1996). A user's guide to basalt discrimination diagrams. In: Wyman, D. A. (ed.) Trace Element Geochemistry of Volcanic Rocks: Applications for Massive Sulphide Exploration. Geological Association of Canada, Short Course Notes 12, 79-113.

[32] Ndema Mbongue J. L., Ngnotue T., Ngo Nlend C. D., Nzenti J. P., Suh C. E. (2014). "Origin and Evolution of the Formation of the Cameroon Nyong Series in the Western Border of the Congo Craton." Journal of Geosciences and Geomatics, vol. 2, no. 2 62-75. doi: 10.12691/jgg-2-2-4.

[33] Owona, S., Schulz, B., Minyem, D., Ratschbacher, L., Tchamabe, B. C., Olinga, J. B., Ekodeck, G. E. (2022). Eburnean/Trans-Amazonian orogeny in the Nyong complex of southwestern Cameroon: Meta-basite geochemistry and metamorphic petrology. Journal of African Earth Sciences, 190, 104515.

[34] Fitton, J. G., James, D., Kempton, P. D., Ormerod, D. S., Leeman, W. P. (1988). The role of lithospheric mantle in the generation of late Cenozoic basic magmas in the western United States. J. Petrol. 1, 331-49.

[35] Pearce, J. A. (1983). Role of the sub-continental lithosphere in magma genesis at active continental margins. In: Hawkeswoeth, C. J. and Norry, M. J., (Eds), Continental basalts and mantle xenolithes. Nantwich: Shiva, 230-249.

[36] Wilson, M. (1989). Igneous petrogenesis, Unwin Hyman Ltd., London, UK.

[37] Nédélec, A., Minyem, D., Barbey, P. (1993). High-P—high-T anatexis of Archaean tonalitic grey gneisses: the Eseka migmatites, Cameroon. Precambrian Res. 62, 191-205.

[38] Nédélec, A., Nsifa, E. N., Martin, H. (1990). Major and trace element geochemistry of the Archaean Ntem plutonic complex (South Cameroon): Petrogenesis and crustal evolution. Precambrian Res. 47, 35-50.

[39] Shang, C. K., Satir, M., Siebel, W., Nsifa, E. N., Taubald, H., Liégeois, J. P., Tchoua, F. M. (2004). TTG magmatism in the Congo craton; a view from major and trace element geochemistry, Rb–Sr and Sm–Nd systematics: case of the Sangmelima region, Ntem complex, southern Cameroon. J. Afri. Earth Sci. 40, 61-79.

[40] Ganwa, A. A., Frisch, W., Siebel, W., Ekodeck, G. E., Shang, C. K., Ngako, V. (2008). Archean inheritances in the pyroxene–amphibole-bearing gneiss of the Méiganga area (Central North Cameroon): Geochemical and 207Pb/206Pb age imprints. C. R. Geosci. 340, 211- 222.

[41] Pearce, J. A., Harris, N. B. W., Tindle, A. G. (1984). Trace-element discrimination diagrams for the tectonic interpretation of granitic rocks. J. Petrol. 25, 956-983.

[42] Martin, H. (1994). The Archean grey gneiss and the genesis of continental crust. In Developments in Precambrian Geol. 11, 205-259.

[43] Sylvester, P. J. (1994). Archean granite plutons. In Developments in Precambrian Geol. 11, 261-314.

[44] de Souza, Z. S. R., Martin, H., Peucat, J. J., de Sa, E. F. J., Macedo, A. H. F. (2007). Calc-Alkaline Magmatism at the Archean-Proterozoic Transition: the Caico Complex Basement (NE Brazil). J. Petrol. 48, 2149-2185.

[45] Ako, T. A., Vishiti, A., Suh, C. E., Kedia, A. C., Omang, O. (2018). Trace and Rare Earth Elements Patterns in Metamorphosed Ultramafic Rocks of the Paleoproterozoic Nyong Series, Southeast Cameroon. International J. Mining Sci. 4, 10-24.