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Original Article

Geochemistry, Petrogenesis and Tectonic Signification of the I-Type Granitoids in Ladde-Gore (Northern-Domain, North Cameroon)

Amadou Diguim Kepnamou[1], Yaya Fodoué[2], Mahamat Abakar[2], Wassouo Wadjou Jacques[2]

[1]*Department of Earth Science and Environment, Faculty of Sciences, University of Garoua, Cameroon.*
[2]*Institut for Geological and Mining Research, Centre for Geological and Mining Research of Garoua, Cameroon.*

[1]*Corresponding Author : kepnamoudiguim@yahoo.fr*

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Abstract *- The Ladde-Gore region is located in the northern domain of the Pan-African chain in Cameroon. The present work deals with the petrography and geochemistry of the granitoids of the Ladde-Gore region. The granitoids in the study area consist of amphibole granite, amphibole-biotite granite, amphibole-biotite-muscovite granite, and granodiorite. These rocks have a grainy texture with a primary paragenesis of Amp+Bt+Pl+Ort+Mic+Qz+Ap+Zr and a secondary paragenesis of Ep+Chl+Op. The Ladde-Gore granitoids are magnesian to slightly ferriferous, shoshonitic to calco-alkaline hyper-potassic, metaluminous, and belong to type I granitoids. Rare Earth profiles (REE) show a negative Eu anomaly for the granodiorite and no Eu anomaly for the granites. Multi-element spectra show positive or negative Ba anomalies for some samples and negative Nb-Ta, Sr, Zr, and Ti anomalies. The process behind the formation of these rocks is fractional crystallization. These rocks were emplaced in a VAG subduction environment (volcanic arc granitoids).*

Keywords *- Petrography, geochemistry, Ladde-Gore, Northern domain, Central Panafrican Fold Belt.*

1. Introduction

The Central African Pan-African Chain (CPAC) (Figure 1) is an elongated, E-W-trending mega-orogenic belt that spans Nigeria, Cameroon, Chad, and the Central African Republic [1, 2] and extends to NE Brazil in the Borborema province, forming the Brazilian Chain [3, 4, 5, 6, 7]. The Central African Pan-African Range (CPAC) subdivided in Cameroon into three domains [8]: the Northern Domain, the Central or Adamaoua-Yadé Domain and the Southern Domain (Fig. 2). The study area belongs to the northern domain of the Pan-African chain of Central Africa (Fig. 2). The Pan-African formations in the Northern Domain have been studied by several authors [9, 10, 11, 12, 13, 14] who show that they consist of semi-pelitic, conglomeratic, quartzite and volcaniclastic rocks with associated bimodal tholeiitic volcanism. Metamorphism shows evidence of evolution from granulite to amphibolite facies. The Ladde-Gore region is the northern domain of the Central African Pan-African Chain (CPAC). Work in the north of the domain is generally delineated by sector. Previous studies, often very local and limited, are typically separated by vast areas with little or no exploration. What is more, this work consists of geological surveys accompanied by mainly petrographic descriptions and very little geochemical information. The virtual absence of precise and detailed geochemical data on the Ladde-Gore area means that it is not possible to establish exact correlations with other work carried out in this field. The aim of the present work is to contribute to the understanding of the geodynamic evolution of the Northern Domain and of the Central African Pan-African Chain (CAPC) in general through the petrographic and geochemical study of the Ladde-Gore granitoids.

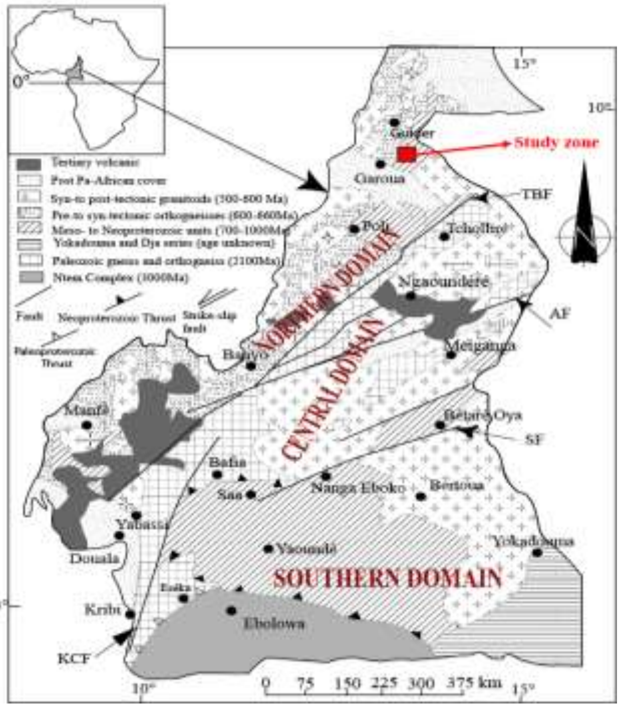

Fig. 1 Geological map of the Pan-African Fold Belt (PAFB) of the North Congo craton showing the study area (simplified after [8])

2. Geological Setting

Most of Cameroon has been stabilized since the Pan-African, a major thermo-tectonic event that affected much of the African continent between around 900 and 550 Ma [15, 16]. Numerous regional synthesis studies [8, 17, 18, 19] relating to the structural, petrographic, geochemical, and geochronological characteristics of this chain have made it possible to distinguish a North Cameroon domain, the Central or Adamaoua-Yadé domain, and the Southern domain (Figure 2). Based on Sm-Nd isotope data, [17] place the boundary between the North and Central domains at the Tcholiré-Banyo fault. Our study area is located in the northern domain. Synthesis work [2, 17] shows that the Pan-African chain of the North Cameroon domain is made up of five units:

1. The schist unit is composed of metabasalts and metarhyolites interbedded in a volcanic-sedimentary sequence. These rocks correspond to the epi-metamorphic Poli series and its equivalent. The U-Pb age of the metarhyolites in this suite is 830 Ma and is considered to approximate the extensional phase associated with the opening of the basin [20].
2. The schist unit is composed of metabasalts and meta-rhyolites interbedded in a volcano-sedimentary sequence. These rocks correspond to the epi-metamorphic Poli series and its equivalent [20].
3. The gneiss unit is composed of metagrauwackes of volcanic-clastic origin. They are associated with orthogneisses and amphibolites. D1 and D2 metamorphism affect these two lithological units and present a concordant tectonic contact. They differ only in the degree of metamorphism, which is greenschist to amphibolite facies for the schists and high-temperature amphibolite facies for the gneisses [21, 22].
4. The syn-to tardi-tectonic D1 granitoids (630-620 Ma) consist of metadiorites and metagranodiorites and correspond to the BIP (basic to intermediate metadiorite and metagranodiorite) of [20]. They are placed in schists and gneisses and often contained in enclaves. For example, the most extensive outcrops are found in the SE of Bibémi, at Pitoa (Guebaké) and Guider (Ekola Gorge).
5. The late-tectonic D2 granitoids (~560-540 Ma) correspond to leucocratic granites and syenites with variable structures (aplitic to porphyritic) that outcrop in the form of domes or inselbergs that cut across the D2 regional structure and dominate the relief. Examples include the Godé, Mindif, Kaélé, and Guider massifs.

Petrographic and geochemical analyses of the granitoids in the Ladde-Gore sector will enable us to gain a better understanding of the context in which the granitoids in the area were placed and to integrate the results to understand the geodynamic model of the entire northern domain.

3. Methodology

3.1. Petrography

The petrographic study began at the field scale and sample scale, which allowed for the macroscopic identification of the facies of the granitoids and the constituent minerals of each rock type. Thin sections of the rock samples were made at the Faculty of Sciences of the Department of Earth Sciences at the University of Yaoundé I in Cameroon.

3.2. Geochemistry

The ICP-AES (Inductively Coupled Plasma - Atomic Emission Spectroscopy) quantification technique determined selected samples' major, trace, and rare earth elements content at ACME Analytical Laboratories (Vancouver, Canada). It was carried out using the alkaline fusion method, which involved 200 mg of each sample mixed with 900 mg of lithium metaborate ($LiBO_2$).

The mixture is then dissolved in a nitric acid (HNO_3) solution. The major elements, expressed as oxides, were determined by emission spectrometry, while the trace elements were determined by mass spectrometry.

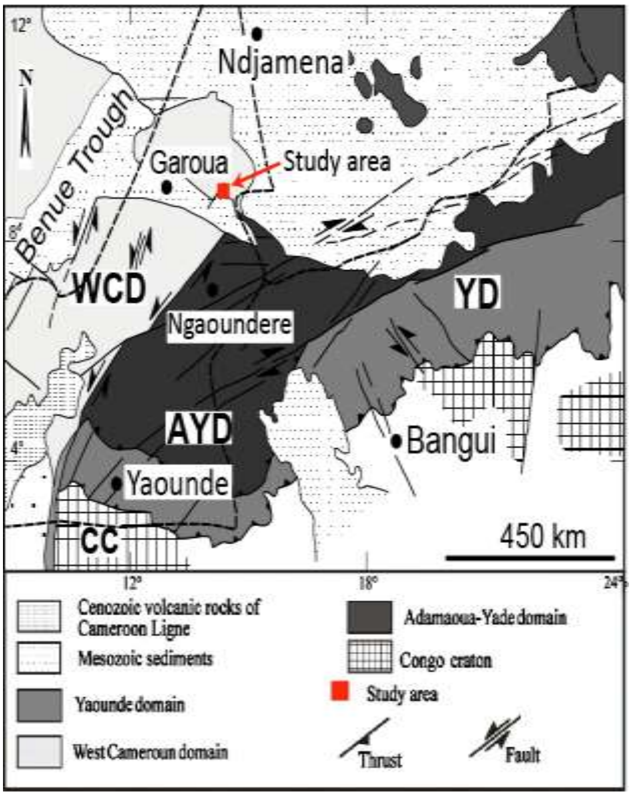

Fig. 2 Geological Map of Cameroon [17] Showing the Major Groups. AF, Adamawa Fault; KCF, Kribi-Campo Fault; SF, Sanaga Fault; TBF, Tcholliré-Banyo Fault. The large domains are [23] and [24]. The study area is represented by the black rectangle NE of Garoua. Inset: Cameroon's position in Africa

4. Results

The results presented were petrography and geochemistry on the total rock.

4.1. Petrographic Study

The granitoids of the Ladde-Gore locality essentially comprise amphibole granite, Amphibole and biotite granite, Amphibole, Biotite, and muscovite granite, and granodiorite. The outcrops explored are shown in Figure 3.

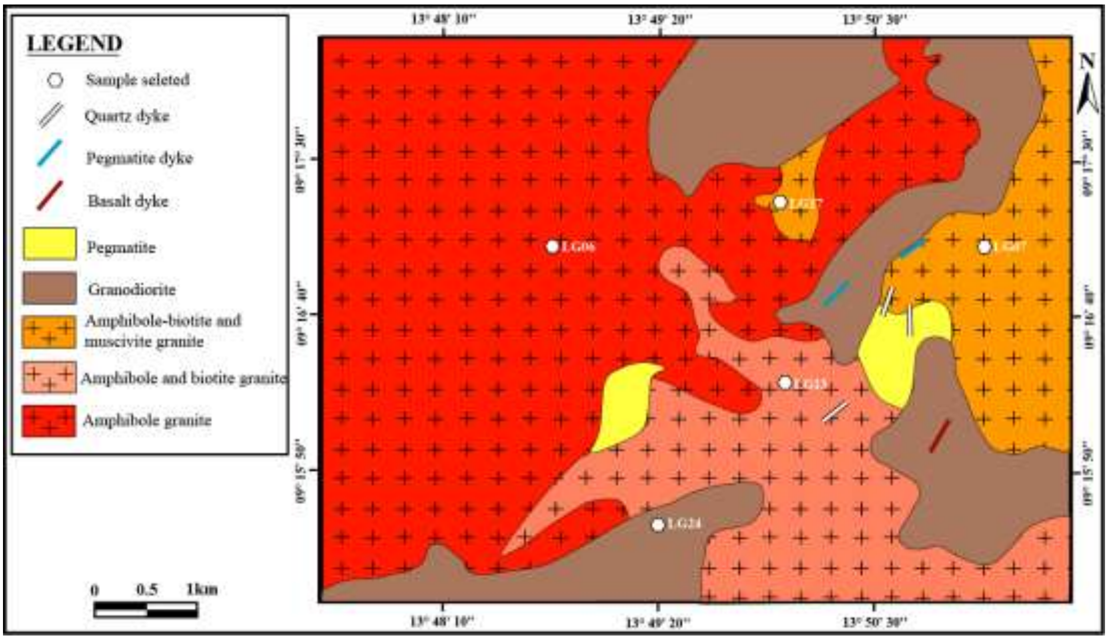

Fig. 3 Outcrop Map of Ladde-Gore region

4.1.1. Amphibole Granite

Amphibole granite outcrops in slabs (Figure 4a) and in centimetric to diametrically scattered blocks in the Ladde-Gore savannah. The blocks are arranged and elongated in an N30E direction. The rock has a grey weathering patina. The LG6 slide and rock were examined under the microscope. The rock has a grainy texture (Figures 4b and 4c) consisting of the following minerals: Amphibole, orthoclase, Plagioclase, microcline, Quartz, zircon, epidote, and opaque minerals. Amphibole is a green hornblende that occupies around 15% of the rock's total volume. Its sub-automorphic to xenomorphic crystals (fig. 4b) vary in size from around 0.5mm to 2mm. Some amphibole crystals contain quartz inclusions and opaque minerals. Orthoclase accounts for around 15% of the rock's total volume. Orthoclase crystals are sub-automorphic to xenomorphic, ranging from 1mm to 2.5mm. This orthoclase is perthetic with quartz ex-solutions. Orthoclase crystals are always associated with Plagioclase and Quartz. Plagioclase forms polycrystalline, sub-automorphic, and xenomorphic patches ranging in size from 0.5mm to 4.5mm. Plagioclase occupies around 10% of the rock's total volume. Some plagioclase crystals show polysynthetic macles that sometimes end at an angle on the mineral. Plagioclase transforms into sericite and also displays sub-microscopic inclusions. Microcline occurs as sub-automorphic to xenomorphic polycrystalline patches, accounting for around 10% of the rock's total volume. Microcline minerals have average sizes of around 3.5 mm (Figure 4b). Quartz occupies around 25% of the rock weight, with sub-automorphic crystals ranging from 0.8mm to 3mm in size. Epidote, brownish-greenish to pinkish in colour and xenomorphic in form, accounts for around 15% of the rock's total volume. It results from the alteration of Amphibole. Automorphous zircon (hexagonal) forms a crystal approximately 0.02mm in size, automorphous epidote (rounded), and opaque minerals forming the dark minerals of the rock are the accessory minerals of the rock and represent a total of 10% of the rock's weight.

4.1.2. Amphibole and Biotite Granite

Amphibole-biotite granite outcrops in slabs and blocks in the savannah. The weathering patina is grey and measures millimetres (Figure 4d). Under the microscope, slide LG13 was cut into the rock. The rock has a grainy texture (Figure 4e) and consists of the following minerals: Amphibole, Biotite, orthoclase, Plagioclase, Quartz, and opaque minerals. Amphibole (15%) is a green hornblende with sub-automorphic to xenomorphic crystals varying in size from around 0.5mm to 3mm. Some amphibole crystals include opaque minerals. Biotite (10%) forms brown flakes varying in size from approximately 0.8mm to 1.5mm. In some places, Biotite turns into chlorite (Figure 4f), associated with Amphibole. Plagioclase (20%) forms mineral patches varying in size from 0.7mm to 4mm. Plagioclase features double macles (single Carlsbad H1 and polysynthetic). Orthoclase (35%) is perthitic (fig. 4f) and forms automorphic to sub-automorphic crystals ranging in size from 1mm to 4mm. Some orthoclase crystals have sub-microscopic inclusions, while others include opaque minerals. Orthoclase is always associated with Plagioclase and Quartz. Quartz (10%) comprises automorphic, sub-automorphic, and xenomorphic crystals ranging in size from 0.5mm to around 2mm. Quartz is often found to be an inclusion in Biotite. Opaque minerals are the dark minerals of the rock and represent 10% of the rock's weight.

4.1.3. Amphibole, Biotite, and Muscovite Granite

The Amphibole-biotite-muscovite granite outcrops in scattered, metric to decametric blocks in the Ladde-Gore savannah. The blocks are arranged and elongated in an N68E direction. The rock sample (Figure 4g) is grey with a grey-to-whitish weathering patina and an average thickness of 1.5mm.

Under the microscope, the LG7 and LG17 slides have been cut into the rock. The rock has a grainy texture and consists of the following minerals: Amphibole, Biotite, Muscovite, orthoclase, Plagioclase, Quartz, chlorite, zircon, and opaque minerals. Amphibole (10%) is a green hornblende forming sub-automorphic crystals with an average size of around 2.5mm. It is always associated with Biotite. Biotite (15%) forms sub-automorphic to xenomorphic flakes ranging in size from 0.2 mm to 2 mm. It is always associated with Amphibole and occurs as inclusions in some plagioclase crystals. Muscovite (5%) forms flakes of the same size as Biotite. Its purplish-pink can be recognised as a sparkling-blue polarization hue (fig. 4h). Muscovite is always associated with Biotite and forms the rock's two micas together.

Orthoclase is perthitic, accounting for around 35% of the rock's weight. It is formed of automorphic to sub-automorphic crystals ranging in size from 0.5mm to 4mm. Plagioclase (15%) consists of automorphic to sub-automorphic crystals ranging in size from 0.4mm to around 2.5mm. Plagioclase crystals feature macles that terminate at an angle on the mineral (fig. 4i). Plagioclase is associated with Quartz in the rock.

Plagioclase has zircon inclusions (Figure 4i). Quartz (10%) forms sub-automorphic to xenomorphic crystals ranging in size from 0.5mm to 2mm. In places, it is found embedded in orthoclase. Chlorite (10%) forms flakes the same size as Biotite and can be recognized by its greenish polarization hue (Figure 4f). Biotite is formed by biotite alteration. Opaque minerals (5%) form the dark minerals of the rock. Some opaque minerals are embedded in orthoclase.

4.1.4. Granodiorite

Granodiorite outcrops in slabs and boulders in the savannah and the river bed (Fig. 4j) north of the village of Laddé-Gorré. Boulders range from decimetric to metric in size. The weathering patina of the rock is grey. The thin sheet LG24 was cut in granodiorite. At the scale of the thin slide, the rock has a grainy texture. It consists of Amphibole, Biotite, quartz, Plagioclase, orthoclase, chlorite, apatite, and opaque minerals. Amphibole (15%) is a green hornblende with a sub-automorphic form varying in size from 0.4 to 1.5mm. Some amphibole crystals have the simple H1 Carlsbad-type macle (fig. 4k). Biotite (10%) occurs as dark brown to light brown flakes varying in size from 0.8 to 1.2 mm long by 0.4 mm wide. Biotite is associated with Amphibole and opaque minerals. Quartz (20%) forms patches varying in size from 0.5 to 2.5 mm. It is xenomorphic and shows rolling extinction. It is associated with the rock's feldspars. Plagioclase (25%) forms crystals averaging 0.5 to 1 mm in length. Plagioclase crystals are sub-automorphic. Plagioclase is zoned (Figure 4l) and transforms into sericite. Orthoclase (15%) forms crystals of almost the same size as plagioclase crystals. It is sub-automorphic and associated with Plagioclase, Quartz, and opaque minerals. Chlorite (5%) forms at the expense of Biotite and is also associated with Amphibole and opaque minerals in the rock. Accessory minerals include apatite and opaque minerals. Apatite (3%) forms automorphic (rounded) to sub-automorphic crystals averaging 0.3 mm in length. Apatite is found to be an inclusion in Plagioclase. Opaque minerals (7%) are found to be an inclusion in Amphibole, Plagioclase, and orthoclase.

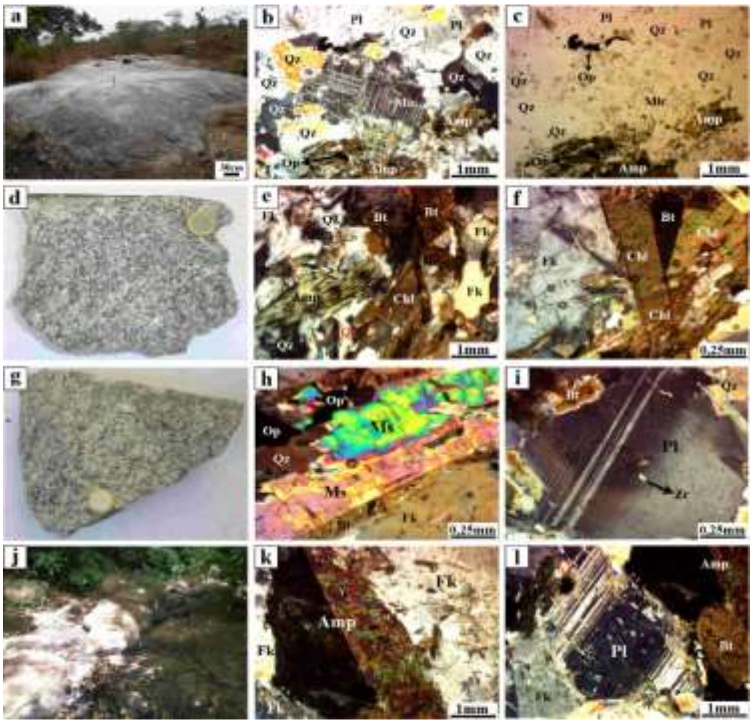

Fig. 4 Photographs of outcrops and microphotographs of thin sections of the Ladde-Gore rock. a) Slab outcrop of amphibole granite; b) Grained texture of amphibole granite (LPA); c) Grained texture of amphibole granite (LPNA); d) Sample of amphibole granite and Biotite with grained texture; e) Coarse-textured amphibole-biotite granite (LPA); f) Biotite transforming into chlorite (LPA); g) Coarse-textured amphibole-biotite-muscovite granite sample; h) Muscovite flake with scintillating polarization hue (LPA); i) Plagioclase with polysynthetic macles ending in bevel with zircon inclusion (LPA); j) Slab and boulder outcrop of granodiorite in streambed; k) Amphibole with single Carlsbad macle (LPA); l) Plagioclase with zonation in centre (LPA).

4.2. Geochemistry Study

Chemical analyses of the sample rock of Ladde-Gore granitoids are given in Table 1.

Table 1. Major (wt%) and trace element (ppm) in the Ladde-Gore granitoids

Rock	Amphibole granite	Amphibole-biotite and muscovite granite		Amphibole and biotite granite	Granodiorite
Sample	**LG6**	**LG7**	**LG17**	**LG13**	**LG24**
SiO_2	70.69	70.04	70.73	67.35	64.14
TiO_2	0.24	0.36	0.16	0.49	1.11
Al_2O_3	15.08	14.94	15.09	15.25	14.59
Fe_2O_3	2.66	2.93	1.96	4.68	6.25
MgO	0.76	1.04	0.68	1.22	2.07
CaO	2.57	2.36	2.23	2.69	2.43
Na_2O	4.21	4.21	3.65	4.51	2.91
K_2O	2.98	3.47	4.93	2.82	4.87
P_2O_5	0.10	0.11	0.07	0.23	0.40
MnO	0.03	0.03	0.03	0.06	0.06
LOI	**0.30**	**0.20**	**0.10**	**0.40**	**0.50**
SUM	**99.89**	**99.88**	**99.90**	**99.84**	**99.63**
Na_2O+K_2O	7.19	7.68	8.58	7.33	7.78
Na_2O/K_2O	1.41	1.21	0.74	1.60	0.60
A/CNK	1.02	1.00	0.98	0.99	1.01
A/NK	1.91	1.85	1.60	1.92	1.50
FeOt	2.40	2.64	1.77	4.22	5.63
Cs	0.30	0.50	0.30	0.50	1.80
Rb	49.40	87.20	82.60	71.40	140.70
Ba	2429.00	1455.00	2212.00	1091.00	2405.00
Sr	444.80	365.70	378.80	450.10	319.80
Pb	1.10	1.50	1.10	1.40	2.70
Th	2.10	11.40	4.90	7.70	13.20
U	0.10	0.90	0.30	0.20	1.20
Zr	192.60	178.30	122.60	248.20	1113.10
Hf	4.50	5.50	3.30	5.70	25.40
Ta	0.10	0.60	0.20	0.40	1.20
Y	4.30	16.00	11.80	13.50	63.90
Nb	1.80	14.20	3.10	8.90	30.40
Sc	4.00	4.00	6.00	6.00	7.00
Cr	19.00	32.00	20.00	18.00	40.00
Ni	20.00	21.00	20.00	20.00	20.00
Co	4.80	7.00	4.10	8.50	11.10
V	27.00	35.00	18.00	55.00	72.00
W	0.50	0.50	0.50	0.50	0.50
Ga	15.50	18.70	14.70	17.30	18.50
Zn	26.00	35.00	16.00	46.00	88.00
Cu	6.70	36.30	2.20	6.40	10.40
La	22.30	44.50	28.30	66.60	168.00
Ce	36.50	59.10	44.80	114.60	346.50
Pr	3.52	7.89	5.10	13.49	43.38
Nd	12.40	27.30	17.50	46.30	170.10
Sm	1.88	4.29	3.36	6.68	28.10
Eu	0.97	0.92	0.89	1.62	3.06
Gd	1.45	3.64	3.22	4.64	21.56
Tb	0.17	0.49	0.45	0.55	2.68
Dy	0.95	2.70	2.36	2.77	13.53
Ho	0.16	0.55	0.45	0.47	2.39
Er	0.39	1.57	1.22	1.21	6.08
Tm	0.06	0.20	0.15	0.16	0.78

Yb	0.39	1.34	0.98	1.10	4.49
Lu	0.06	0.21	0.14	0.15	0.61
Ti	1430.16	2145.24	953.44	2919.91	6614.49
Eu/Eu*	1.79	0.71	0.83	0.89	0.38
(La / Yb)N	38.84	22.56	19.62	41.13	25.42
(Gd / Lu)N	2.99	2.14	2.84	3.82	4.37
(Nb/Zr)N	0.15	1.25	0.40	0.56	0.43

4.2.1. Classification and Nomenclature

The classification diagram of [25], adapted to plutonic rock by [26], was used to discriminate the samples from the study area (Figure 5). Samples from rock in the area fall into the granite and granodiorite field and into the sub-alkaline rock domain.

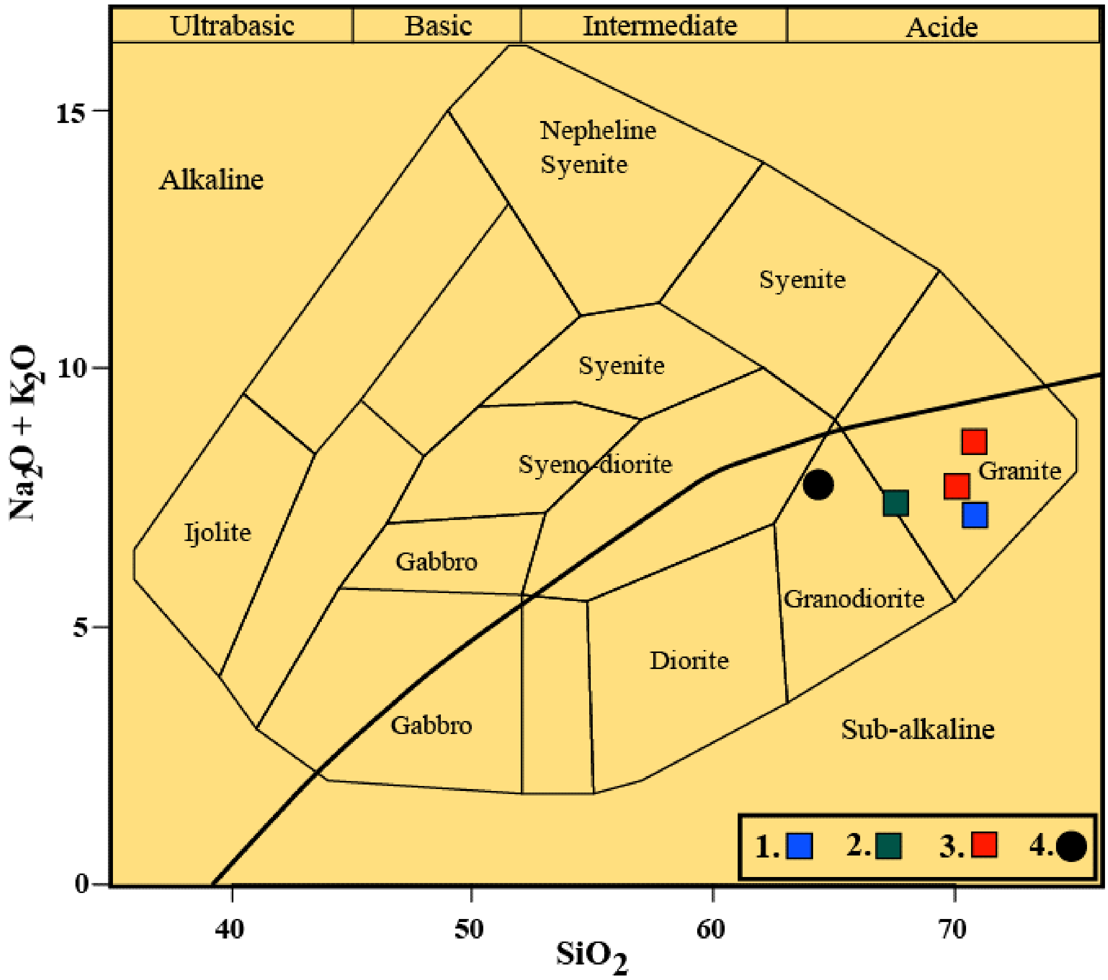

Fig. 5 Classification of plutonic rock in the [25] diagram, adapted to plutonic rock by [26]. The bold line limits the fields of alkaline and sub-alkaline rock. This limit is from [27]. 1. Amphibole granite; 2. Amphibole-biotite granite; 3. Amphibole-biotite-muscovite granite; 4. Granodiorite

4.2.2. Geochemical Characterization

The plutonic rocks of the Ladde-Gore region are characterized by a variation in oxide weight: 64.14 - 70.73% SiO_2; 14.59 - 15.25% Al_2O_3; 2.82 - 4.93% K_2O; 1.96- 6.25% Fe_2O_3; 2.91 - 4.51% Na_2O; 2.23 - 2.69% CaO; 0.68 - 2.07% MgO; 0.03-0.06% MnO; 0.16 - 1.11% TiO_2 and 0.07 - 0.40% P_2O_5. The sum of alkalis (Na_2O + K_2O) varies between 7.19 and 8.58%, and the Na_2O/K_2O ratio varies between 0.60 and 1.60. Overall, the plutonic rocks analyzed are characterized by medium to high Ba (1091-2429 ppm), low Sr (319.80 - 450.10 ppm), and low Rb (49.40 - 140.70 ppm).

In the K_2O vs SiO_2 diagram by [28] (Fig. 6a), granite samples occupy the field of rocks in the shoshonitic series and the hyperplastic calc-alkaline series.

[29] A/NK vs A/CNK diagram (fig. 6b) for these rocks indicates an Al_2O_3 / (Na_2O+ K_2O) or A/NK molar ratio of between 1.50 and 1.92 and an Al_2O_3 / (CaO+Na_2O+ K_2O) or A/CNK molar ratio of between 0.98 and 1.02. This diagram shows that the rock in the area is metaluminous in nature and belongs to the type I granitoids.

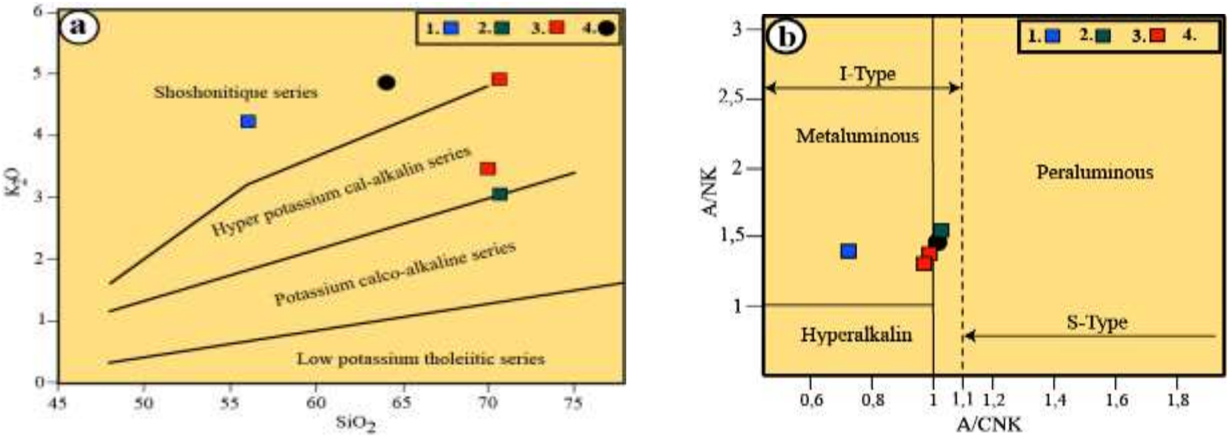

Fig. 6(a) a- Diagram of K_2O as a function of SiO_2 used to discriminate rocks in the Ladde-Gore region. Series limits are from [28]; b- Positions of rocks from the Laddé Goré locality in the [29] diagram. A/NK = Al_2O_3 / (Na_2O+ K_2O); A/CNK = Al_2O_3 / (CaO + Na_2O + K_2O) in mole. The boundaries between I and S granites are from [30]. 1. Amphibole granite; 2. Amphibole-biotite granite; 3. Amphibole-biotite-muscovite granite; 4. Granodiorite.

4.2.3. Magmatic Tendency

In the FeO / (MgO+FeO) versus SiO_2 diagram of [31] (Figure 7), the plutonic rocks of the study area show that three (03) samples are moderately ferriferous and magnesian, and two (02) are magnesian.

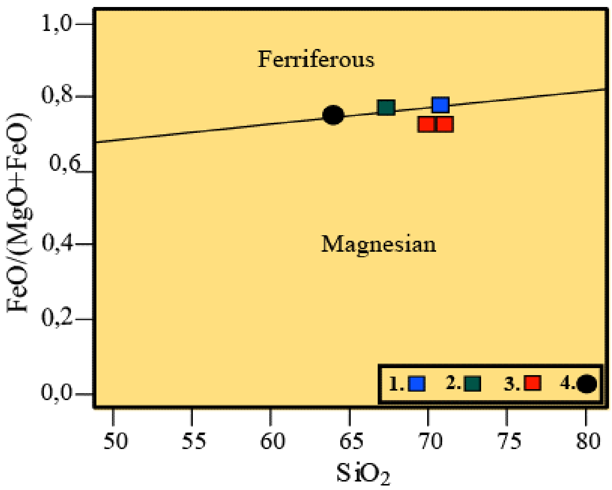

Fig. 7 Diagram FeO / (MgO+FeO) as a function of SiO_2 from [31], showing the ferriferous and magnesian domain; d1. Amphibole granite; 2. Amphibole-biotite granite; 3. Amphibole-biotite-muscovite granite; 4. Granodiorite.

4.2.4. Geochemistry Evolution

The geochemical evolution is based on major, trace, and rare earth elements.

Majors and Traces Elements

In [32] type variation diagrams for major elements (Figure 8), points representative of granitoids in the Ladde-Gore region show a decrease in Al_2O_3, Fe_2O_3, MgO, TiO_2, and P_2O_5 with increasing SiO2 content. Na_2O and K_2O vary little and show no correlation with increasing SiO_2 content.

[32], diagrams of some trace elements as a function of silica (Figure 9) show a linear regression with increasing SiO_2 content for the elements Rb, Th, Ta, Zr, Y, and V and a representative dispersion of points for the elements Ba and Sr.

Rare Earth Elements (REE) and Multi-Elements

Geochemical evolution will be based on the study of variations in trace elements and rare earths. Rare-earth spectra normalized to chondrites and the primitive mantle, according to [33] values for plutonic rocks from the Laggé-Goré region (Fig. 10), show almost identical parallelism, slope, and jaggedness. They are characterized by more significant enrichment in Light Rare Earth Elements (LREE) than in Heavy Rare Earth Elements (HREE).

The rare earth spectra of the samples studied from the Ladde-Gore region (Figure 10a) show strong fractionation $[(La/Yb)_N = 19.62 - 41.13]$ and almost flat Heavy Rare Earth Elements (HREE) profile segments $[(Gd/Lu)_N = 2.14 - 4.37]$. All granite samples (LG6, LG7, LG13, and LG17) show no Eu anomaly (Eu/Eu* = 0.71 - 1.79), while the granodiorite sample (LG24) shows an Eu anomaly (Eu/Eu* = 0.38).

The multi-element spectra (Figure 10b) all show spectra with a negative Ta-Nb and Ti anomaly and a positive Ba anomaly. However, only one sample of amphibole-biotite-muscovite granite does not show a Ba anomaly.

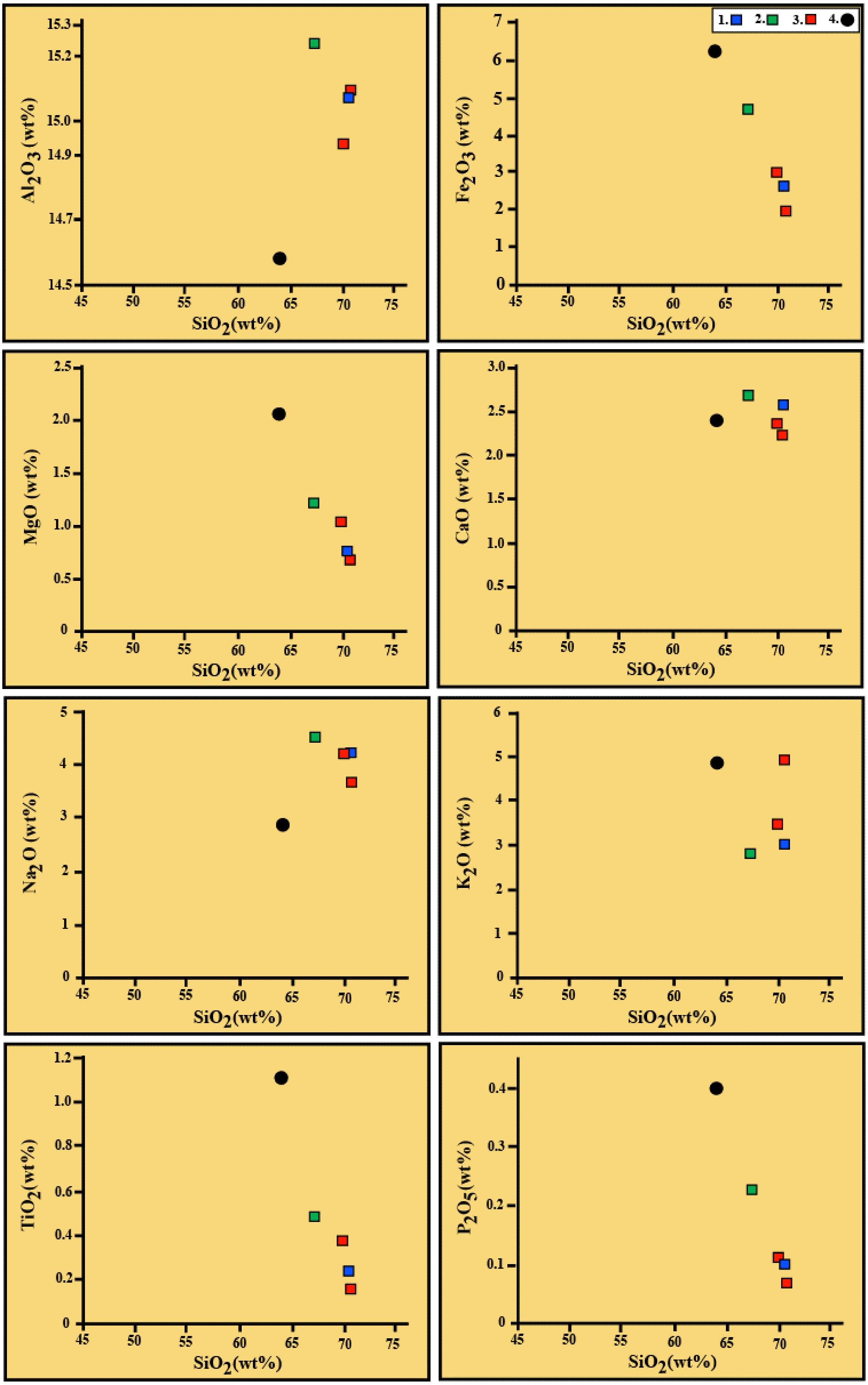

Fig. 8 [32] Diagram of Ladde-Gore granitoids, showing the variation of oxides versus SiO_2. 1. Amphibole granite; 2. Amphibole-biotite granite; 3. Amphibole-biotite-muscovite granite; 4. Granodiorite

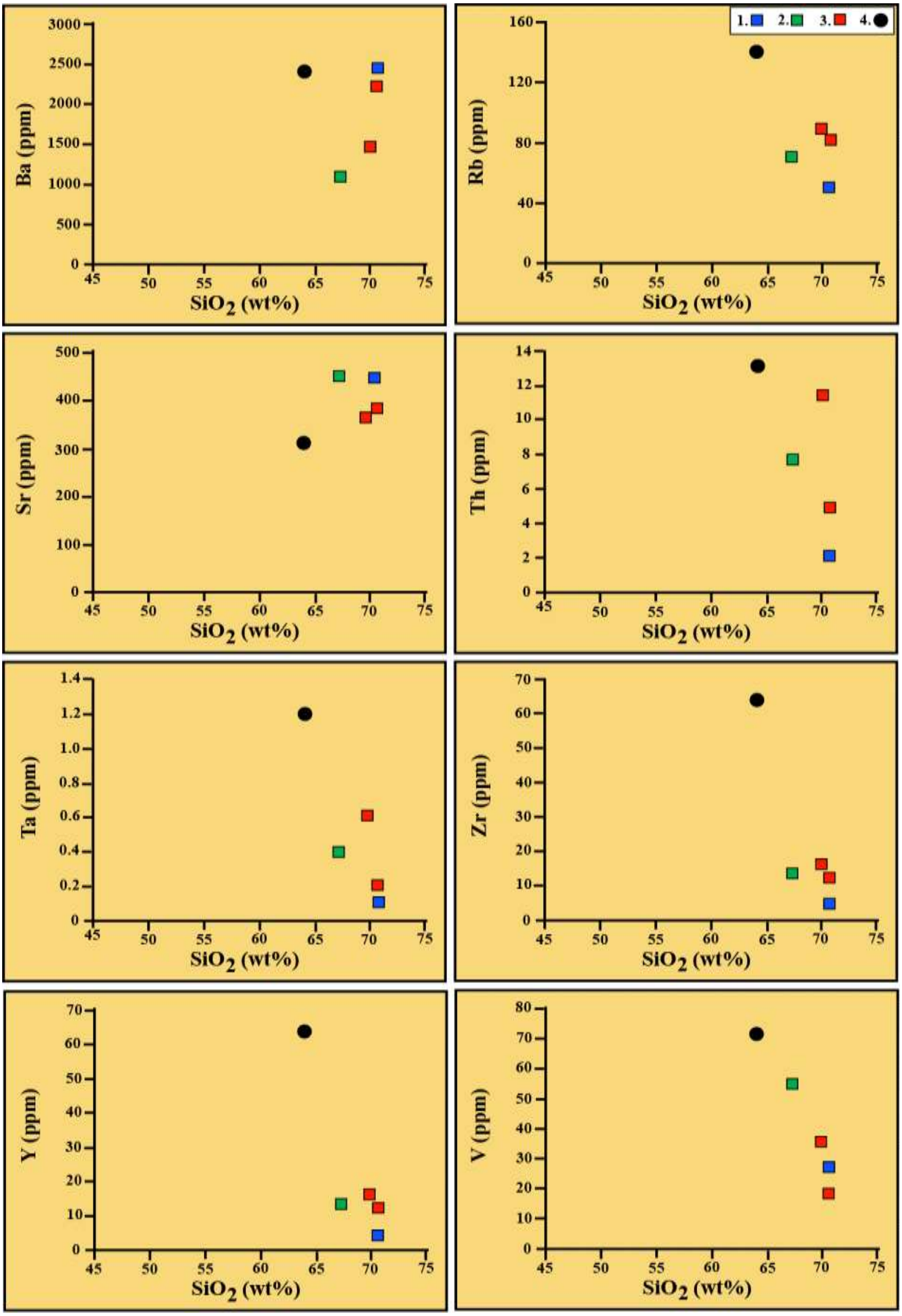

Fig. 9 [32] Diagram of sum trace elements of Ladde-Gore granitoids. 1. Amphibole granite; 2. Amphibole-biotite granite; 3. Amphibole-biotite-muscovite granite; 4. Granodiorite

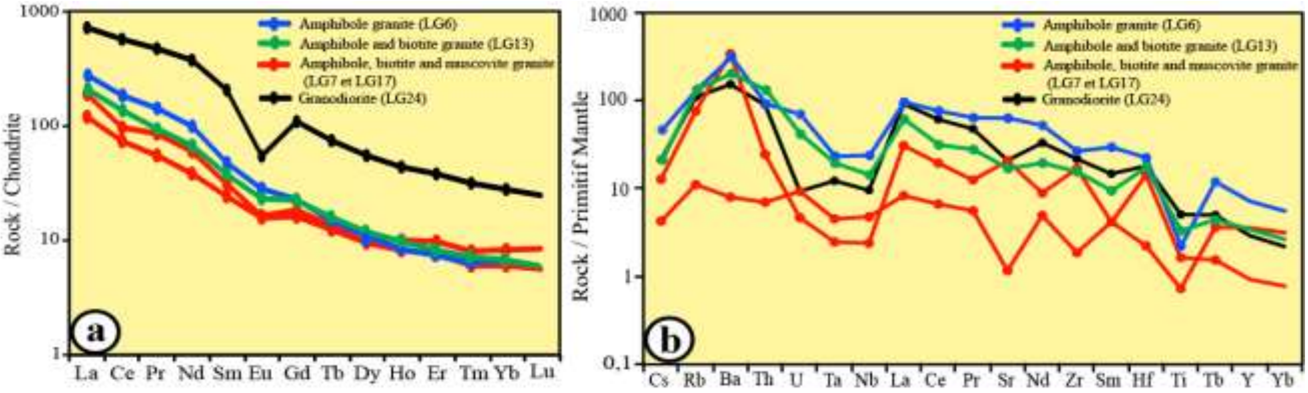

Fig. 10 Rare-earth (a) and multi-element (b) spectra of plutonic rock from the Ladde-Gore region normalized to chondrites and primitive mantle by [33]

5. Discussion

5.1. Petrography

The Ladde-Gore granitoids have a grainy texture. Microscopic observations show that the minerals crystallize in the following order: zircon, apatite, Amphibole - Plagioclase - Biotite - microcline - orthoclase - muscovite - Quartz. Granitoids of the same or similar composition have been described in several areas of the North Cameroon region. These include the Kaélé [14], Poli [17], Guider [34], and other regions.

5.2. Geochemistry

The Ladde-Gore rock nomenclature classifies the samples in the granite and granodiorite fields (cf. Figure 5). These rocks are calc-alkaline, hyperpotassic and shoshonitic (cf. Figure 6a), magnesian to moderately ferriferous (cf. Figure 7), metaluminous and belong to type I granitoids (cf. Figure 6b). Rocks with similar characteristics have been described in several areas of the North Cameroon domain of the Central African Pan-African chain.

The distribution of major elements in the [32] diagram (see Figure 8) shows a linear correlation for the Ladde-Gore granitoids. The linear trend towards a negative correlation between SiO_2 and the oxides Al_2O_3, Fe_2O_3, MgO, TiO_2, and P_2O_5 reflects the intervention of fractional crystallization processes [35, 36]. Fe_2O_3 and MgO decrease reflects the fractional crystallization of early ferromagnesian silicate minerals and titanium oxides [37, 38]. The approximately linear distribution of elements also reflects the intervention of fractional crystallization processes or mixing between mafic and felsic magmas [39, 40].

The parallelism of the rare earth profiles suggests that the Ladde-Gore granitoids are co-genetic and have undergone the same evolutionary process [41, 42] (Heinhorst *et al.*, 1996; Zoheir *et al.*, 2008). Light Rare Earth Enrichment (LREE) (see Figure 10a) indicates the fractionation of accessory minerals such as apatite, while heavy earth depletion (HREE) is attributed to the fractionation of zircon [43]. The negative Eu anomaly observed in the granodiorite sample reflects plagioclase fractionation during the evolution of the parent magma [44]. The absence of a negative Eu anomaly in granites despite the presence of Plagioclase in these rocks can be explained by the fact that the Eu may not have been incorporated into the Plagioclase and may reflect strong oxidation conditions where all the Eu is in the form of Eu^{3+} or limited fractionation of the Plagioclase in the source [45]. This observation was also made for the Guider granitoids by [34] and the Kaélé granitoids [14]. The abundance of ferromagnesian minerals such as Amphibole in the rocks suggests, on the one hand, that the melting that took place had a magmatic source of mantle origin [46].

Multi-element spectra of Ladde-Gore granitoids generally show positive Ba and Hf anomalies and negative Ta-Nb, Sr, Zr, and Ti anomalies. The pronounced negative Nb-Ta anomalies are classically interpreted as corresponding to the characteristics of rocks derived from continental crust [47, 48]. The positive Sr anomaly in some multi-element spectra may be linked to these rocks' high proportion of Plagioclase [44]. The negative Ti anomaly would indicate the crystallization of ferro-titanium minerals. The opaque minerals observed in these rocks would then be ferrotitanium or gold mineralization.

Discriminant diagrams of Rb as a function of (Ta + Yb) and Ta function Yb by [49] show that all rock samples from the study area are in the volcanic arc granitoïd range (Figures 11a and 11b). The discriminant diagram of [50] confirms the disposition of the Ladde-Gore sample in the domain of the Volcanic Arc Granitoids (VAG).

Amphibole-biotite-muscovite granite is metaluminous and belongs to type I granitoids. This characteristic shows that the muscovite crystals observed in the rock are primary. The primary Muscovite in this granite reflects the rock's alumina richness and mantle origin [51]. It should be noted that, with a few exceptions, all the rocks studied show a negative Ta-Nb, Sr, and Ti anomaly and sometimes a positive Ba anomaly. These are the characteristics of the rock of Mantelic origin. Recognized I-Type granitoids with the same characteristics have been described in the Kaélé region [14], the Guider region [34], the Bafoussam region [52], the Doua region [53], and the Baïbokoum-Touboro-Ngaoundaye region [54].

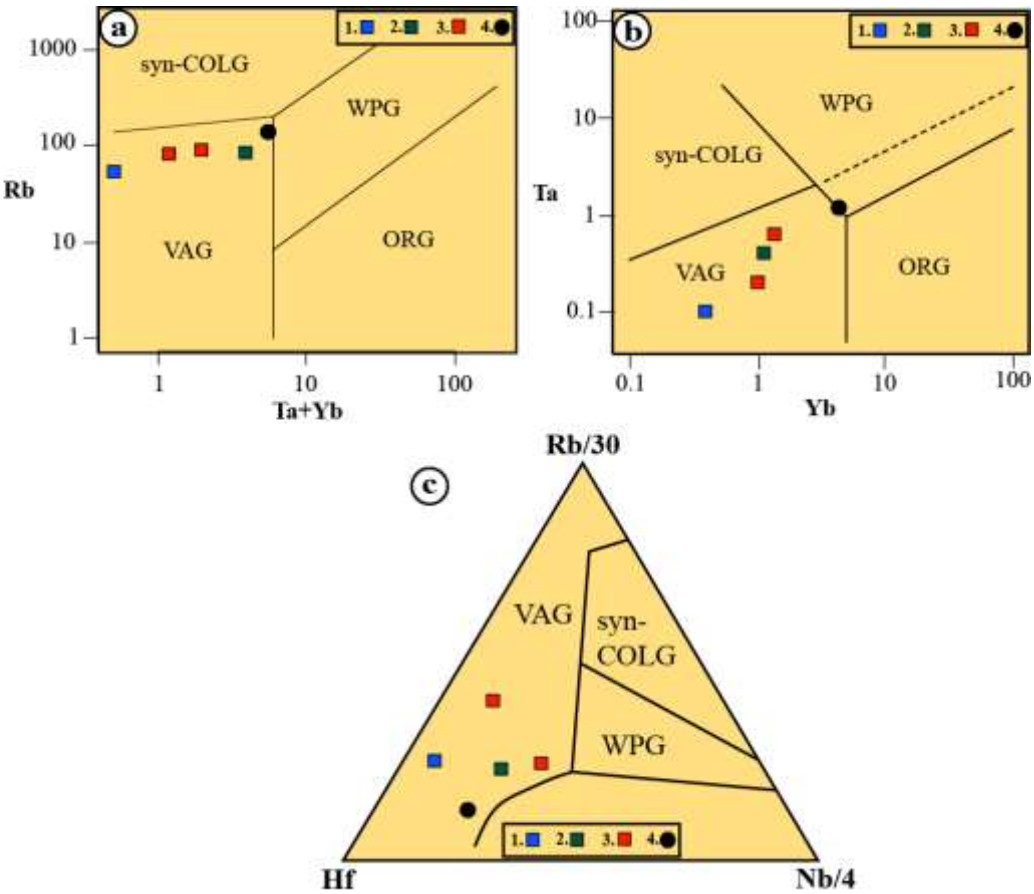

Fig. 11 (a) Position of the Ladde-Gore granitoïd in the tectono-discriminant diagrams Rb as a function de (Ta + Yb) of [49]; (b) Tectono-discriminant diagrams Ta as a function Yb of [49]; (c) Discrimination diagram of the Geotectonic setting after [50]. VAG : Volcanic Arc Granitoïd ; WPG : Within plate Granitoïd; ORG : Oceanic Ridge Granitoïd ; Syn-COLG : Syn-Collisional Granitoïd. 1. Amphibole granite; 2. Amphibole-biotite granite; 3. Amphibole-biotite-muscovite granite; 4. Granodiorite.

6. Conclusion

The granitoids of the Ladde-Gore region include amphibole granite, amphibole-biotite granite, amphibole-biotite-muscovite granite, and granodiorite. These rocks have a granular to porphyritic texture. The primary minerals are Amp+Bt+Pl+Ort+Mic+Qz+Ap+Sph+Zr, and the secondary minerals are Ep+Chl+Ser+Op. The geochemical study of the Ladde-Gore granitoids shows that these rocks comprise granites and granodiorite. These rocks are magnesian to slightly ferriferous, calc-alkaline, potassic to strongly potassic, metaluminous, and belong to type I granitoids. These rocks are formed by fractional crystallization. The Ladde-Gore granitoids are enriched in Light Rare Earth Elements (LREE) compared with Heavy Rare Earth Elements (HREE) and in LILE (Large Ion Lithophile Element) compared with HSFE (High Field Strength Element). They have negative Eu anomalies at varying intensities, and some granite samples have no anomalies. These are rocks of crustal origin with negative Ta-Nb, Sr, and Ti anomalies and a positive Ba anomaly. These granitoids are emplaced in a subduction to a syn-collisional environment (volcanic arc granitoids).

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