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Petrographic and Geochemical Characteristics of the Granitoids in the South of Godé (North of the Square Degree of Léo-Burkina Faso, West Africa)

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Abstract

South of Godé, in the central-western region of Burkina Faso, granitoids of Paleoproterozoic age are similar to those of the Man/Leo shield. This study focused on the petrographic and geochemical characteristics of these granitoids, with the following results: 1) The tonalite that outcrops in the south-west of the study area belongs to the TTG group or first generation granitoids. They are most often ribboned at outcrop and have a geochemical signature close to that of Archean TTGs. Tonalite has a metaluminous character and the REE spectrum indicates that it may be derived from partial melting of basic magmatic rocks. 2) Biotite granites have no outcrop structure. They are weakly metaluminous to peraluminous and potassic to highly potassic. Their rare earth spectra indicate that they may be derived from the partial melting of TTG granitoids. 3) Geotectonic diagrams show that the granitoids studied to the south of Godé were emplaced in an active tectonic context similar to that of present-day subduction zones.

Keywords

Burkina Faso, Godé, Man/Leo Shield, Petrography, Geochemistry, Partial Melting, Geotectonic Setting

1. Introduction

In the Paleoproterozoic formations of the Baoulé-Mossi domain of the Man/Léo ridge (Figure 1), the metavolcanites and metavolcano sediments are intruded by a large volume of granitoids emplaced during the Eburnian orogeny [1] [2] [3] [4]. Radiometric ages show that granitoids were emplaced continuously during this period and are distinguished by their petrographic and geochemical characteristics [1] [4] [5]. The earliest granitoids show geochemical affinities with Archean TTGs or Andean adakites. While Tonalite-Trondjhemite-Granodiorite granitoids (or TTG granitoids) are emplaced in a progressively cooling crust, most calc-alkaline potassic granitoids are emplaced in a context of transcurrent tectonics. Calc-alkaline granitoids are metaluminous to peraluminous and are often intrusive in TTG granitoids [1] [6] [7]. The geodynamic processes of emplacement are not unanimously accepted. Several studies have already proposed the geotectonic contexts and petrogenetic processes that contributed to the emplacement of TTG granitoids and calc-alkaline granitoids [1] [6] [7] [8]. The present study focuses on similar granitoids located south of the village of Godé in the Léo square degree of Burkina Faso (Figure 2). The aim of this preliminary study is to help define the mineralogical and geochemical compositions of these granitoids. These different compositions will also help to constrain the geodynamic processes that prevailed when these granitoids were emplaced. Further studies could be carried out to properly characterise the internal structures of

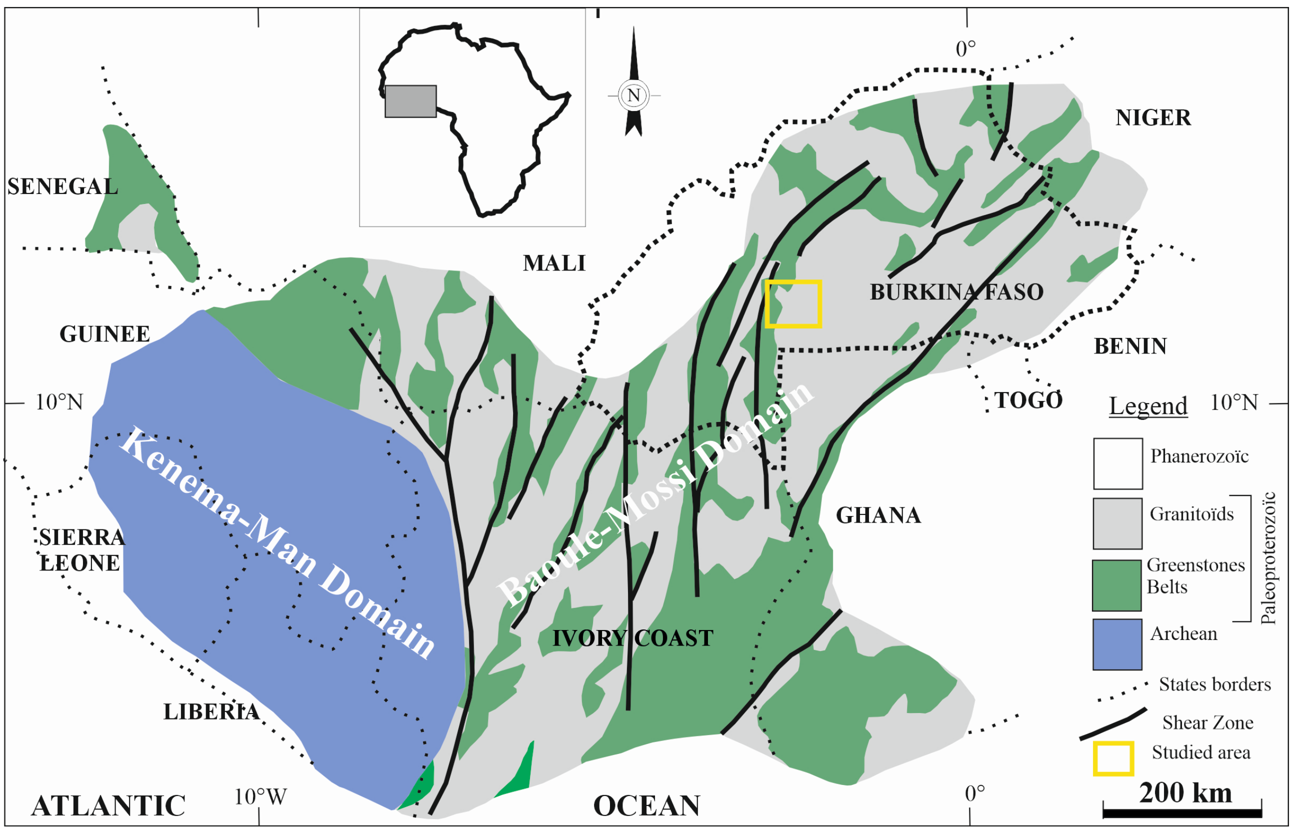


Figure 1. Position of the synthetic geological map of Burkina Faso on the Man/Leo shield.

these granitoids and help to better constrain their emplacement process.

2. Geological Setting

The study area is located in the central west of Burkina Faso, north of the square degree of Léo, between 2.31˚ and 2.45˚ west longitude and between 11.88˚ and 11.99˚ north latitude (**Figure 2**). Like the entire Baoulé-Mossi domain [9]-[17], the Paleoproterozoic formations in the study area (**Figure 2**) are metavolcanic, metaplutonic and metasedimentary rocks that are grouped within the Boromo greenstone belt, which has a submeridian mean trend. Various granitoid intrusions cut this belt.

South of the village of Godé (**Figure 2**), the Palaeoproterozoic formations are essentially granitoids similar to those described by [1] and [7], which are TTG-type granitoids and biotite granitoids. Overall, in the Léo square degree, TTG granitoids constitute the first generation of granitoids and are those described by [1] as the internal tonalitic domain with ages between 2150 and 2140 Ma. There are also biotite granites and porphyritic biotite granites, which are younger than the TTG granitoids and constitute the second generation of granitoids. On a

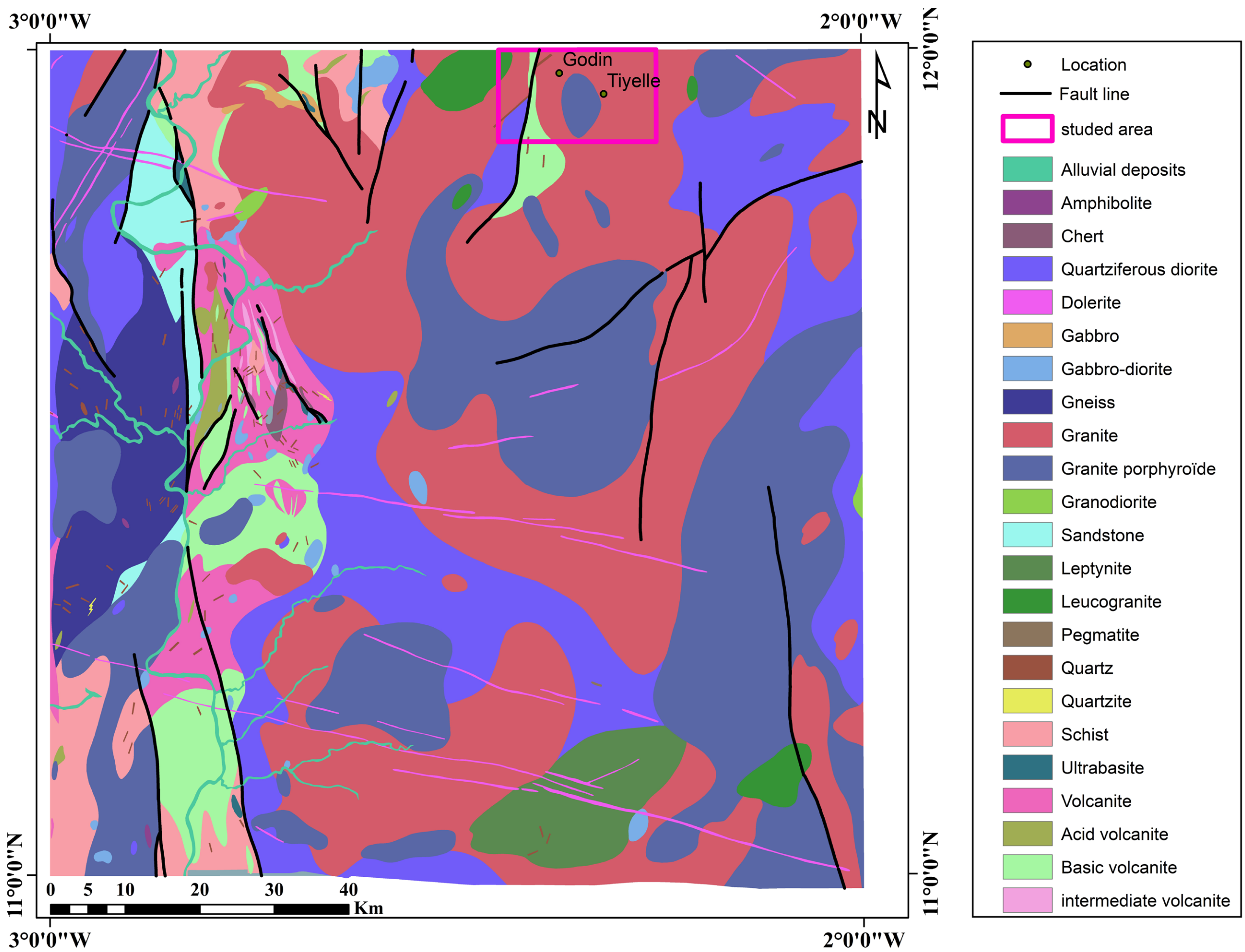


Figure 2. Position of the study area on the Léo square degree geological map.

field scale, TTG granitoids are generally foliated and the ferromagnesian silicates are amphibole and biotite. Biotite granites and porphyritic biotite granites are apparently isotropic and contain biotite as the only ferromagnesian silicate. The first generation of granitoids has affinities with Archean TTGs and the second generation of granitoids is calc-alkaline [1] [6] [7].

3. Methodology

In the field we used a sampling grid with a maximum spacing of 2 km, as long as outcrop conditions allowed. Samples were described macroscopically and, where the rocks were deformed, structural measurements were made using a compass and clinometer. Twenty (20) thin sections were prepared in the laboratory and examined under a polarising microscope. The selection of samples for whole rock geochemical analysis was guided by the small variations in mineralogical and/or textural composition that appeared during microscopic observations. A total of four (04) samples were analysed, including one (01) for tonalite, which belongs to the Tonalite-Trondjhemite-Granodiorite granitoids (or TTG granitoids), and three (03) for biotite granite. The whole rock geochemical analysis was carried out at the ALS (Australian Laboratory Services) laboratory in Ireland, which was responsible for all the various sample preparations prior to analysis by Inductively Coupled Plasma Mass Spectrometry (ICP-MS) and Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP-AES). Further information on the methods used by the ALS laboratory is available at www.alsglobal.com. The data provided to us after the analyses covered major, minor and trace elements.

4. Results

4.1. Petrography of the Granitoids in the Study Area

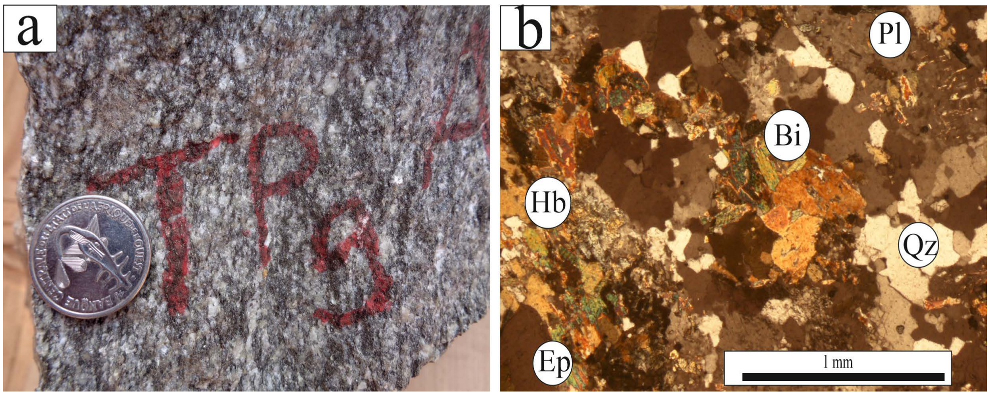
4.1.1. Tonalite

The tonalite represents the TTG granitoids in the study area and makes up most of the bedrock of the biotite granites. At the scale of the outcrop, the tonalite shows a more or less clear ribboned pattern and is dark (**Figure 3(a)**). This colouration is explained by the abundance of biotite and green hornblende.

Microscopically (**Figure 3(b)**), the white minerals are mainly plagioclase, followed by quartz. Potassium feldspars are represented by microcline and occur in very small quantities. Accessory minerals include epidotes, calcite, sphene, zircon and opaques.

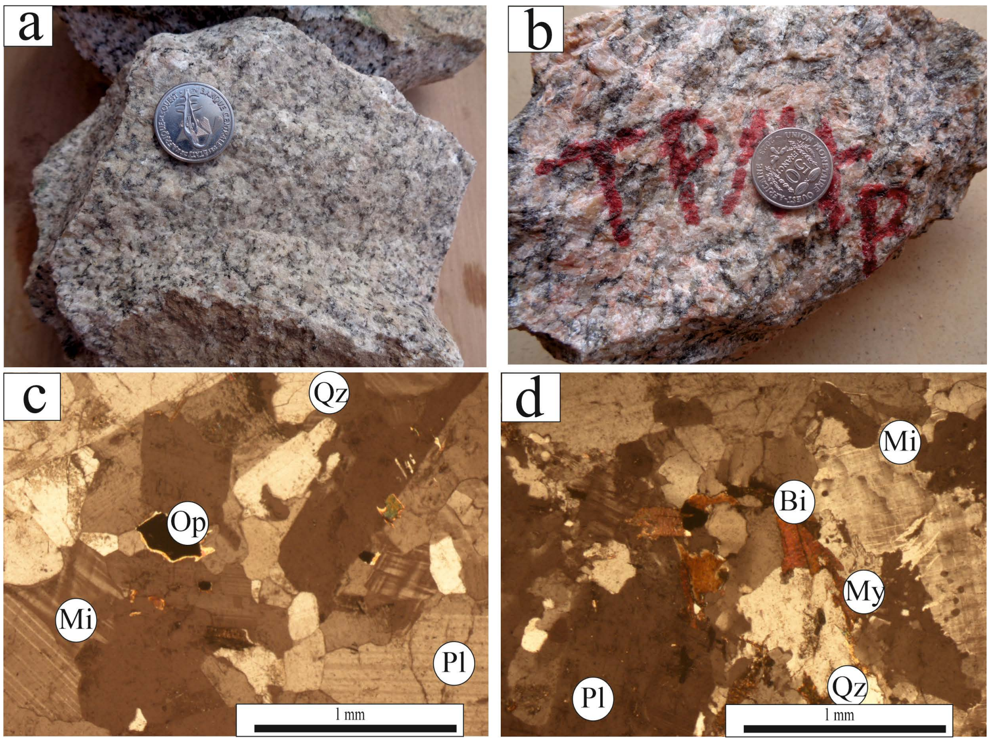
4.1.2. Biotite Granites

In outcrop these are very poorly textured rocks with biotite as the only ferromagnesian mineral. There is a strictly granitic facies with medium crystals (**Figure 4(a)**) and a porphyritic granitic facies with megacrysts of potassic feldspar (**Figure 4(b)**). Overall, both facies are leucocratic and contain more quartz than tonalite. Under the microscope (**Figure 4(a)** and **Figure 4(b)**), quartz is clearly visible in medium-sized crystals with straight extinction. The other white minerals are



Hb: Hornblende; Bi: Biotite; Pl: Plagioclase; Qz: Quartz.

Figure 3. Macroscopic and microscopic view of the tonalite: (a) more or less banded tonalite; (b) microphotograph showing the average mineralogical composition of the tonalite (polarised and analysed light).



Bi: Biotite; My: Myrmékite; Pl: Plagioclase; Mi: Micrcline; Qz: Quartz; Ep: Epidote

Figure 4. Macroscopic and microscopic view of biotite granites: (a) porphyritic facies; (b) medium-grained facies; (c) microphotograph showing the average mineralogical composition of the granites (polarised and analysed light).

plagioclase and potassium feldspar in more or less equal proportions. Accessory minerals are mainly sphene, zircon, epidote and a few opaques.

4.2. Geochemistry of Granitoids in the Study Area

Analyses were carried out on one (01) tonalite sample and three (03) biotite granite samples, including one (01) in the medium grained facies and two (02) in the porphyroid facies. The results of the geochemical analyses (Table 1) show that the silica content of the granitoids in the study area ranges from 66.3% to 74.2%.

Tables 1-3 show the average major, minor and rare earth element compositions of the granitoids in the study area. Changes in the major elements can be assessed by correlating their percentages relative to silica in the various major

Table 1. Major elements in granitoids.

Sample Petrography	TP09 Tonalite	TP10 Biotite Granite	TP13 Biotite Granite	TP14 Biotite Granite
Majors Elements (%)				
SiO_2	66.3	74.2	70.9	73.3
TiO_2	0.41	0.19	0.45	0.23
Al_2O_3	16.25	14.95	14.6	14.65
Fe_20_3T	5.42	1.55	3.28	2.01
MnO	0.08	0.03	0.05	0.03
MgO	2.62	0.33	0.92	0.52
CaO	4.91	1.48	2.32	1.76
Na_2O	3.68	4.86	4.52	4.14
K_2O	2.01	2.94	2.35	4.26
P_2O_5	0.13	0.03	0.15	0.08
Total	101.81	100.56	99.54	100.98
A/CNK	0.95	1.08	1.03	1.00
Norm %				
Q	23.499	31.109	29.7	28.602
C	0	1.153	0.761	0.22
Or	11.879	17.375	13.89	25.175
Ab	31.139	41.124	38.25	35.032
An	21.884	7.147	10.53	8.203
Di	0.398	0	0	0
Hy	6.342	0.822	2.292	1.295
Il	0.171	0.064	0.107	0.064
Hm	5.42	1.55	3.28	2.01
Tn	0.785	0	0	0
Ru	0	0.156	0.394	0.196
Ap	0.308	0.71	0.355	0.189
Sum	101.83	100.57	99.56	100.99

Table 2. Minor elements in granitoids.

Echantillon Pétrographie	TP09 Tonalite	TP10 Granite à biotite	TP13 Granite à biotite	TP14 Granite à biotite
Eléments Mineures (ppm)				
Ba	737	624	575	767
Rb	58.9	115.5	89.4	132
Sr	541	444	668	516
Y	7.5	4.1	5.5	3.2
Zr	110	102	189	141
Nb	3.3	9.02	5.03	3.61
Th	1.67	4.43	6.06	5.79
Ga	17.4	0.44	0.91	0.64
V	94	9	36	18
Cr	42	11	9	10
Hf	2.56	3.05	4.73	3.81
Cs	2.01	2.28	2.51	2.3
Ta	<0.1	0.5	0.1	<0.1
U	0.58	1.68	2.38	1.67
W	0.9	0.7	0.7	0.8
Sn	0.5	1.3	1.1	0.7
Sc	13.4	4.6	6.7	5.6

Table 3. Trace elements in granitoids.

Echantillon Pétrographie	TP09 Tonalite	TP10 Granite à biotite	TP13 Granite à biotite	TP14 Granite à biotite
Terres Rares (ppm)				
La	7.7	14.7	34.6	24.2
Ce	15.7	27.8	68.6	45.8
Pr	2.19	3.27	7.76	5.11
Nd	8.6	11.7	26.7	16.8
Sm	1.88	1.8	3.58	2.64
Eu	0.62	0.44	0.91	0.64
Gd	1.74	1.3	2.45	1.44
Tb	0.24	0.2	0.26	0.14
Dy	1.4	0.86	1.25	0.57
Ho	0.27	0.14	0.19	0.11

Continued

Er	0.9	0.43	0.4	0.24
Tm	0.1	0.05	0.05	0.03
Yb	0.7	0.26	0.36	0.19
Lu	0.11	0.04	0.04	0.03
$\sum$REE	42.15	62.99	147.15	97.94
(La/Yb)N	9	45	77	102
Eu/Eu*	1.03	0.84	0.89	0.91

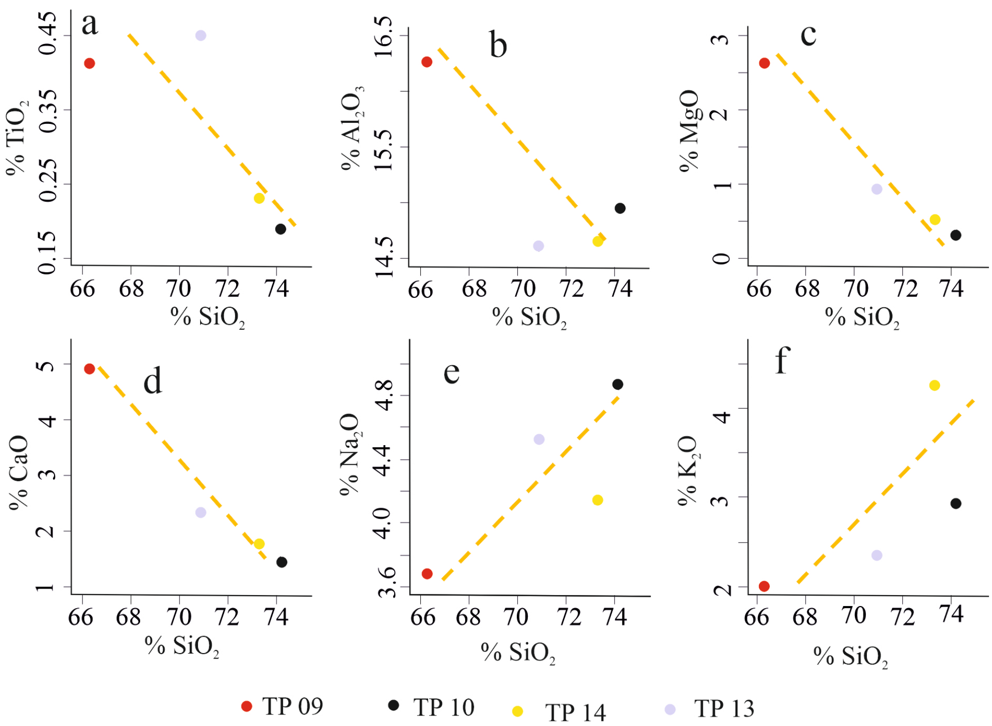


Figure 5. [18] diagrams of majors elements in granitoid.

element Harker plots (**Figures 5(a)-(f)**). As silica increases, elements such as TiO_2, Al_2O_3, MgO and CaO decrease (**Figures 5(a)-(c)**), while Na_2O and K_2O increase (**Figures 5(d)-(f)**). The granitoids are moderately potassic with a K/Na ratio varying between 0.34 and 0.67.

In the mole ratio classification diagram (A/CNK = [Al_2O_3]/[CaO] + [Na_2O] + [K_2O]), the granitoids are type I and are metaluminous to peraluminous (**Figure 6(a)**). Sample TP09, representing tonalite, is metaluminous and the biotite granites (TP10, TP13 and TP14) are peraluminous. In the [19] diagram, these are calc-alkaline to potassic calc-alkaline rocks (**Figure 6(b)**).

Overall, the REE spectra normalised to the C1 chondrite of [20] show relatively high LREE contents (0.44 < LREE < 68.6) compared to HREE (**Figure 7(a)**). This reflects a very good fractionation of the REE spectra, except for tonalite (TP09), which is slightly different from that of the biotite granites. The

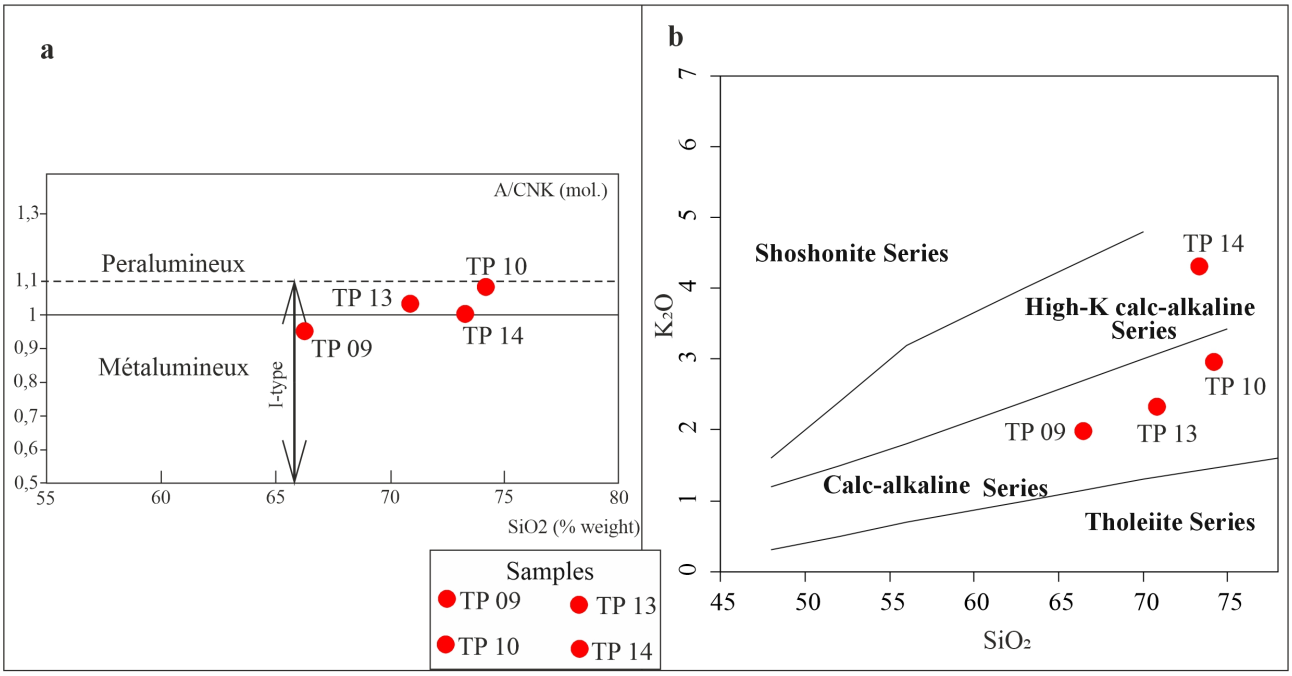


Figure 6. (a) Molar ratio diagram (A/CNK = $[Al_2O_3]/[CaO] + [Na_2O] + [K_2O]$) for granitoids, (b) [19] classification diagram.

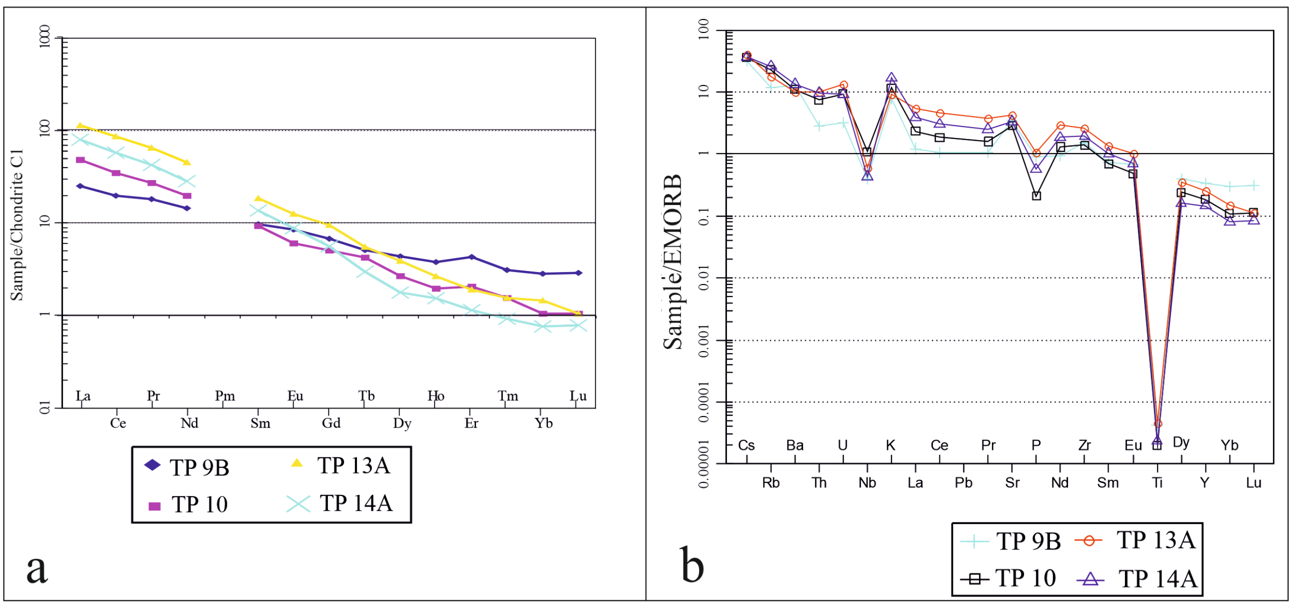


Figure 7. (a) Diagram of REE spectra normalized to the C1 chondrite ([20]) of granitoids, (b) EMORB normalized multi-element diagram ([20]) of granitoids.

$(La/Yb)_N$ ratios are 9 in the tonalite and between 45 and 102 in the biotite granites. The Eu anomaly (Eu/Eu* from 0.84 to 1.03) is practically absent and can be explained by the low fractionation of the plagioclases, especially in the tonalite. However, the granitoids in the study area are rich in Sr and Ba but poor in Ta and Nb (Table 2). These results reflect a good distribution of feldspars and interactions between the different mineral phases.

EMORB standardised multi-element diagrams based on [20] are characterised by an enrichment in LILE (Cs, Ba, K, Sr, Nd) compared to HFSE (**Figure 7(b)**). The profiles are almost parallel and we observe a very pronounced anomaly in Ti and moderate anomalies in Nb, Th and P. Note, however, that the spectrum of tonalite (TP09) shows a slightly elevated anomaly in Th. These different anomalies depend on the fractionation of potassic minerals, ferromagnesians and plagioclases.

These results may indicate a basic magmatic source that fractionated to form the TTG granitoids and then the biotite granites.

In the geotectonic diagrams, the granitoids in the study area are positioned in the domain of syn-plate collision granites (**Figure 8(a)**) or in a volcanic arc environment (**Figure 8(b)**). This indicates that they were also formed in an active tectonic context.

5. Discussion

South of Godé, the outcropping Palaeoproterozoic formations are tonalites and biotite granites, which are clearly distinguished by their mineralogical compositions. Based on the classification diagrams used, the geochemical characteristics of the granitoids in the present study are similar to those studied in Burkina Faso by [6] in the eastern region, [23] in the central-eastern region, [7] in the north-eastern region. The tonalite (TP 09) belongs to the tonalite group described and analysed by [1] and its REE spectrum shows similarities with those of the Archean TTGs. Relatively flat compared with biotite granites, it indicates little plagioclase fractionation. For the category of TTG granitoids, partial melting

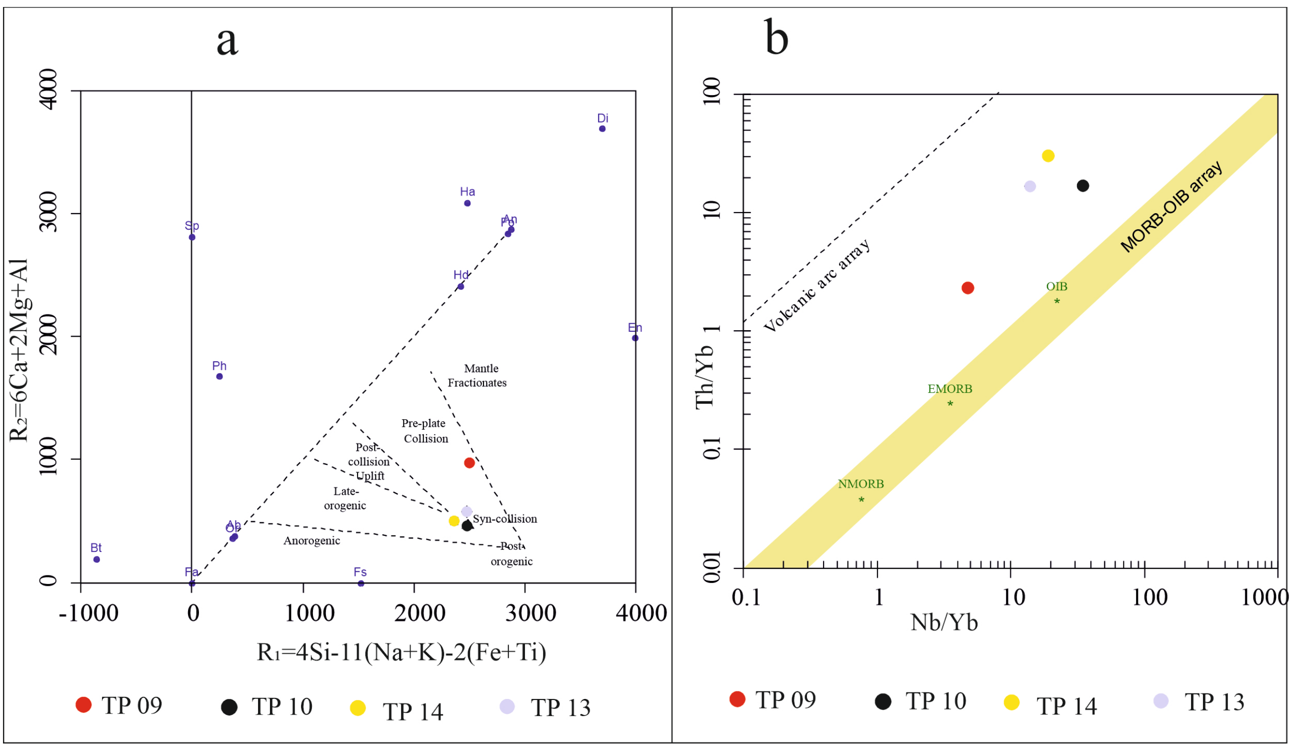


Figure 8. Geotectonic diagrams for granitoids. (a) [21] diagram; (b) [22] diagram.

of basic rocks in a subduction context is suggested [1] [24]. Biotite granites are peraluminous and relatively more potassic, with more fractionated REE spectra. There is a fairly significant enrichment in LREE compared to HREE. With regard to the genesis of biotite granites, [1] use the potassic nature of biotite granites to suggest partial melting of the early TTGs for their genesis. This hypothesis may be corroborated by the leptynites that are often mapped near biotite granites in certain regions of Burkina Faso. Leptynites are metamorphic ribboned rocks whose protoliths are probably early TTG granitoids [25] [26].

The granitoids in the study area are part of a volcanic arc. The TTGs were emplaced by diapirism in the context of regional shortening [8] [27] [28]. The biotite granites are thought to have been emplaced by transcurrence in the form of small coalescing plutons [6]. For the latter, however, [7] suggests the possibility of one or the other of the two emplacement mechanisms. Radiometric ages indicate that the granitoids were emplaced over a long period of time [1] [4] [5].

6. Conclusion

This study presents the petrographic and geochemical characteristics of the Paleoproterozoic granitoids of Godé, in the central-western region of Burkina Faso. The Godé granitoids were emplaced in a subduction context using different emplacement mechanisms. The emplacement mechanisms will be clarified by studying the internal structures of the biotite granites and their immediate host rocks, together with a study of their microstructures. The geochemical characteristics of the biotite granites indicate that they were emplaced by partial melting of previously emplaced TTG granitoids.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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