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Heterogeneous Granitic Pluton of Central Toumodi-Fettekro Sillon (Central Côte d'Ivoire): Petrographic and Geochemical Characterization

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Abstract: The petrographic and geochemical data of the granitoids of the central part of the Toumodi-Fettekro sillon (or belt) have allowed to characterize a complex set whose main terms can be summarized as follows: biotite granites, granodiorites, leucogranites and aplitic bodies. These rocks are composed of quartz, plagioclase, biotite, potassium feldspar, with variable hues (leucocrate to mesocrat), structures (medium to coarse grained) and mineralogical proportions (depending on abundance). The geochemical interpretation is based on the systematic search for genetic links between the various terms of this assemblage. Thus, geochemistry has enabled us to distinguish three facies (biotite granites, leucogranite and aplitic granite) that are weakly altered and peraluminous in character (A/CNK > 1) and a fourth (granodiorite) that tends to be metaluminous (A/CNK < 1). The strongly aluminous character of these three facies and the presence of minerals such as muscovite, garnet and tourmaline, as well as the presence of numerous pegmatite veins, suggest a sedimentary origin (S-type granite). The granodiorite, on the other hand, seems to have genetic links with TTG-type protoliths through a partial fusion process.

Keywords: Granitoid, Volcano-Sedimentary Formation, Birimian, Petrography, Geochemistry, Peraluminous, Sillon

1. Introduction

The Paleoproterozoic domain of the West African Craton contains formations deposited during the Eburnian orogeny (2.1 +/- 0.1 Ga). Although vast, this domain consists of a limited number of lithologies most often affected by greenschist-type metamorphism. The work of Bessoles B. shows that the Birimian is made up of alternating granitic panels and volcano-sedimentary beds [1]. However, the works of scholars group them into four lithological units or ensembles: volcano-plutonic units (gabbros, basalts, andesites, rhyodacites) and volcano-sediments (pyroclastites, and basaltic to rhyodacitic epiclastites) and detrital to sandstone-pelitic sediments locally associated with granitic intrusions [4, 7, 11, 13, 14, 16, 21, 27]. The context of granitoid emplacement (by diapirism or vertical tectonics) in the Birimian is debatable. However, its presence has played an important role in the structuring of volcano-sedimentary sillons, the site of significant orogenic gold deposits [7, 8, 10]. Thus, according to the nature of the magmatic source, we distinguish intraplate granites, arc granites and collusion granites.

Numerous studies based on petrographic, geochemical, geochronological and geotectonic data have led to a typological distinction of Birimian granitoids.

The classification at the scale of Côte d'Ivoire has made it possible to identify a certain number of granitoids: late, peraluminous and S-type granites. Although there is a pile of data on the Toumodi-fettekro trench, there is no real data to characterize the granitoids of the central part of the Toumodi-Fettekro sillon. This work is intended as a contribution to establishing the genetic link between the main facies constituting the heterogeneous granitic pluton that characterize the central part of this sillon.

2. Study Setting

2.1. Geographical Location of the Study Area

Located in the Belier region, more accurately in the center of the Toumodi-fettekro sillon, the study site covers an area of approximately 902 sq.km. It is located between the parallels 6° 54' and 6° 31'30" of North latitude and between the meridians 5° 10'30" and 5°01'30" of West longitude. The relief is generally flat with a few hills occupied by a variation of vegetation (grassy and shrubby savannahs) and rare patches of forest bordering the waterways. It has a warm and humid climate with the N'Zi as its main tributary. The temperature is variable, averaging 26.6°C with annual rainfall of up to 1092 mm.

2.2. Regional and Local Geological Setting

The study area is located in the Baoule-Mossi domain of the West African craton, more exactly in the center of the Toumodi-Fettêkro volcano-sedimentary sillon. This sillon of about 4900 sq.km extends from the south of the Dabakala department to the north of the town of Divo, passing through the autonomous district of Yamoussoukro. It represents one of the seventeen volcano-sedimentary sillon (figure 1) distributed on the Tehini-Dimbokro reference alignments in the east and Ferkessedougou-Soubre in the center, identified in Côte d'Ivoire by Tagini B. and Yace, I., as the place of concentration of the majority of the mineralizations [25, 28]. The geology of the sillon is known from the work of [4, 7, 9, 11, 13, 16, 21, 22, 27]. It is composed of metasedimentary, volcanic and plutonic rocks, sandwiched by granitoids. The heterogeneous Yamoussoukro granite (figure 2) is part of the vast elongated plutonic batholith, which extends from the Burkina border to the southwest of Ivory Coast. It is an undifferentiated, syntectonic granitoid of alumino-potassic chemical composition, interpreted as the last Eburnian event resulting from the subduction-collision of two birimian provinces and marked by the last compressive deformation [25, 29].

3. Method

This study included the collection of several rock samples (granitoids) during the various field visits (figure 2). Thin sections of these rocks were prepared at the Geology, Mineral and Energy Resources Laboratory of the University Felix Houphouët Boigny (Ivory Coast). They were observed with an Olympus BX60 petrographic microscope equipped with 4 magnification objectives, ×5, ×20, ×50, ×100 and an image capture device connected to a computer, in order to identify the main minerals and the nature of the rock. In addition, seventeen samples were selected and sent to Bureau Veritas Commodities in Canada Ltd for geochemical analysis (major and trace elements).

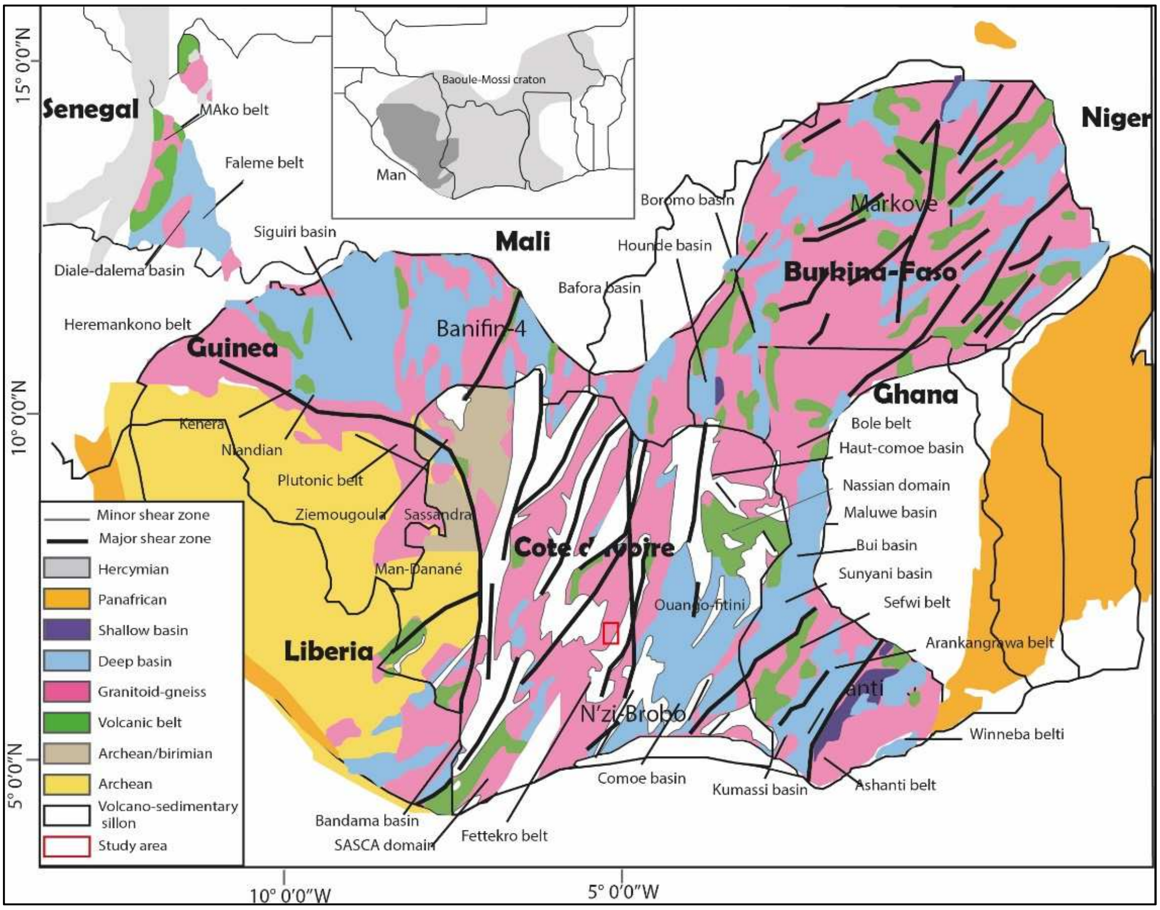

Figure 1. *Synthetic regional geological map of the Man Ridge (Grenholm, 2014) with the different volcano-sedimentary sillon indicating the study area.*

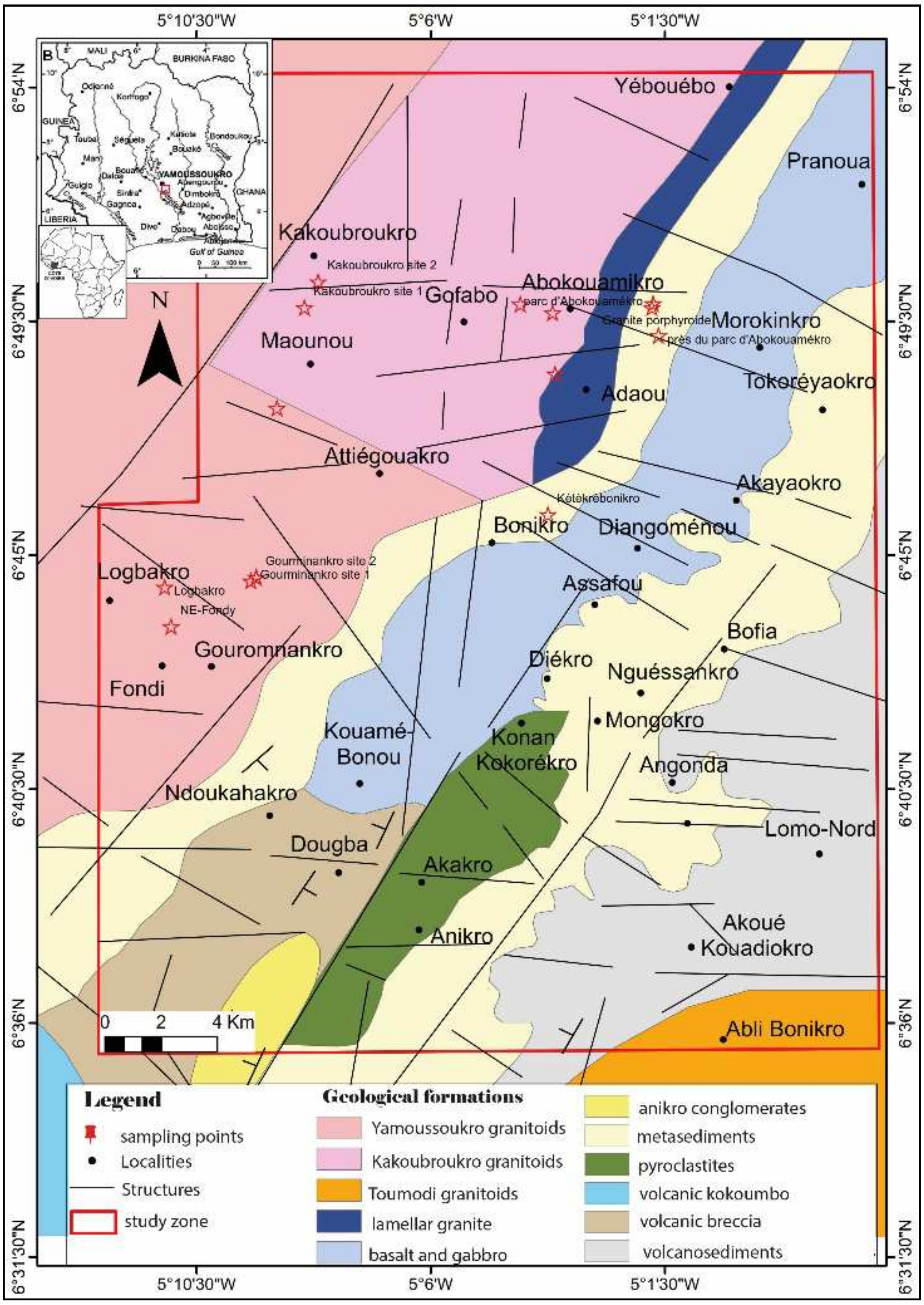

Figure 2. *Geological map of the study area and sampling points for granite samples.*

4. Results and Discussion

4.1. Results

4.1.1. Petrographic Study

The petrographic characteristics of the central sillon granitoids are summarized in Table 1. The different textures and petrographic compositions observed in the granitic intrusive allow us to identify four granitic facies. These are granodiorite, leucogranite, biotite granite and microgranite.

(i). Granodiorite (Grdt)

This rock was observed 1km south of Kakoubroukro and at Abokouamékro, it outcrops as a slab or block, it is rarely found as a rounded or frayed enclave in the biotite granite of Kakoubroukro (Kak01; Abo01) The granodiorite at these two sites shows almost identical texture and deformation, the difference being in the direction of the deformed minerals. At Kakoubroukro the minerals are oriented (N20°-N30°) associated with a banded structure (Figure 3) and at Abokoumékro, the minerals have directions between N30°-N130° reflecting the beginning of metamorphism. It is a mesocratic massif, with a medium-grained grainy texture. It is mainly composed of intergrown minerals consisting of biotite, xenomorphic to sub-automorphic, quartz, xenomorphic, plagioclase, sub-automorphic to automorphic, amphibole (hornblende) and pyroxene. Secondary minerals include chlorite, sericite, epidote, magnetite and opaque minerals. The granodiorite contains micaceous enclaves and is generally crossed by veins of pegmatites (N°125-N°325) and fine-textured leucocratic granites (N°125, N°170 and N50°) with variable thicknesses, as well as numerous quartz veins and veins (N30°-N130°).

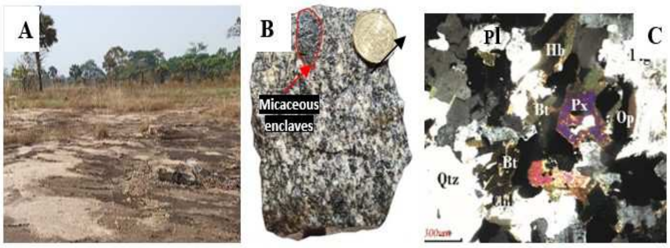

Figure 3. *Macroscopic and microscopic aspects of granodiorite of Kakoubroukro (Kak01) Bt: biotite, Chl: chlorite, Px: pyroxene, Hb: green hornblende, Pl: plagioclase, Qtz: quartz.*

(ii). Biotite Granite (grt-B)

This granite outcrops on all the sites visited, it is present in the form of rounded or extended blocks or in the form of slabs spread out, sometimes over several meters. It is mostly found south of Kakoubroukro, north of Gourminankro, north-east of Logbakro, in Abokouamékro, north-west of Adaou and north-east of Bonikro (Kak02; Gour01; Logba03; Ada; Boni). These rocks show identical mineralogical compositions but different textures. At Kakoubroukro, Gourminankro and Attiegouakro the texture is equigranular fine-grained micrograined with rare phenocrysts (Figure 4). At Bonikro and Logbakro, it has a fine to medium grained texture and a more pronounced alteration at Bonikro with some orientation of the minerals. There is a local association of Bonikro granites with mafic rocks (basalt and gabbro). This granite is mesocratic in color, consisting of fine to medium grains. The primary paragenesis shows that it is composed by order of abondance of quartz, xenomorphic, of variable size (small to medium), of more or less extended biotite, sub-automorphic to automorphic, of plagioclases xenomorphic to sub-automorphic in the form of megacrysts. Muscovites, potassium feldspars (microcline and orthoclase). The accessory minerals are: chlorite, sericite, epidote, magnetite and opaque minerals. In the Gourminankro granite, the presence of biotite clusters and oxidized minerals can be observed.

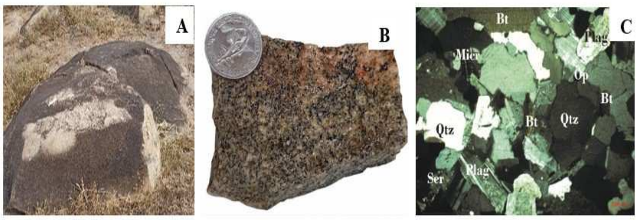

Figure 4. *Macroscopic and microscopic aspects of a biotite microgranite from Gourminankro (gour01); Bt: biotite, Ser: sericite, Micro: microcline, Pl: plagioclase, Qtz: quartz, Op: opaque minerals.*

(iii). Leucogranite or Two-mica Granite (Lgrt)

This facies was observed at several sites in the study area, south of Kakoubroukro, on the Yamoussouko-Attiegouakro axis, NE of Logbakro, at Abokouamekro and Gourminankro. It outcrops in the form of slabs, domes and blocks in predominantly sedimentary formations. It is also found in veins in the Logbakro aplite and in the Gourminankro biotite granite. This rock has a more or less different mineralogy depending on the occurrence of minerals such as biotite and muscovite. A distinction is made between leucogranites with dominant biotite and leucogranites with muscovite dominating over biotite.

1) Leucogranite with muscovites dominant on biotite

This is the leucogranite observed at site 2 at Gourminankro and at site 1 north-east of Logbakro (Figures 5A-B), it outcrops as a slab and/or large block. (Gour02; Logba02). It shows a medium to coarse grained texture, silver in colour due to the abundance of muscovite in the matrix. The mineral paragenesis consists of quartz, xenomorphic with sub-automorphic to automorphic plagioclase phenocrysts, muscovite phenocrysts, sub-automorphic biotites in small quantities, tourmalines, garnet and microcline, the main potassium feldspars. Secondary minerals are: chlorite, sericite, zircon, apatite, orthoclase and opaque minerals.

2) Dominant biotite leucogranite

The dominant biotite leucogranite was observed at site 1 south of Kakoubroukro, on the Yamoussoukro to Attiegouakro axis, south-east of Logbakro (Figures 5D-F), at Abokouamekro. This rock is characterized by an abundance of biotite compared to muscovite. It shows a medium to coarse grained texture with megacrysts of quartz and plagioclase. The main minerals are quartz, potassium feldspar (microcline), xenomorphic to sub-automorphic plagioclase, biotite, muscovite less abundant than biotite and thin tourmalines. Accessory minerals include zircon, chlorite, apatite, monazite, titanite, epidote, ilmenite, titanomagnetite and rutile.

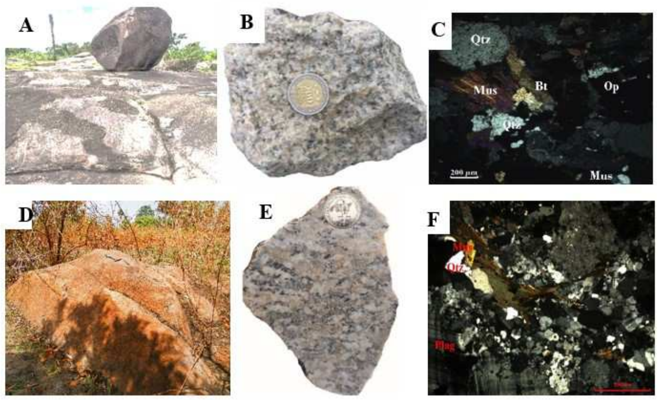

Figure 5. *Macroscopic and microscopic aspects of the dominant muscovite leucogranite (A, B, C) from Logbakro (logba02) and the dominant biotite leucogranite (D, E, F) from Abokouamékro (Abo02) Bt: biotite, Chl: chlorite, Ser: sericite, Mus: muscovite, Pl: plagioclase, Qtz: quartz.*

(iv). Aplite or Microgranite (Mgrt)

This rock has been observed south of Kakoubroukro, in Abokouamekro and southwest of Logbakro (figure 6). It outcrops as a slab or block; it is also found as a vein in the granite of Kakoubroukro and Gourminankro and rarely as an enclave in the biotite leucogranite of Logbakro. It is a leucocratic massif, fine-grained and marked by a schistosity plane. At Logbakro, aplite is the dominant lithology, cut by seams of microdiorite, pegmatites and biotite granites. Its fine texture does not allow us to observe all the minerals with the naked eye, however, coupled with microscopic observation we can see that it is composed of quartz, plagioclases, potassium feldspars, elongated automorphic micas and define the schistosity that affects the rock. As assay minerals we have sericite, titanite and rutile.

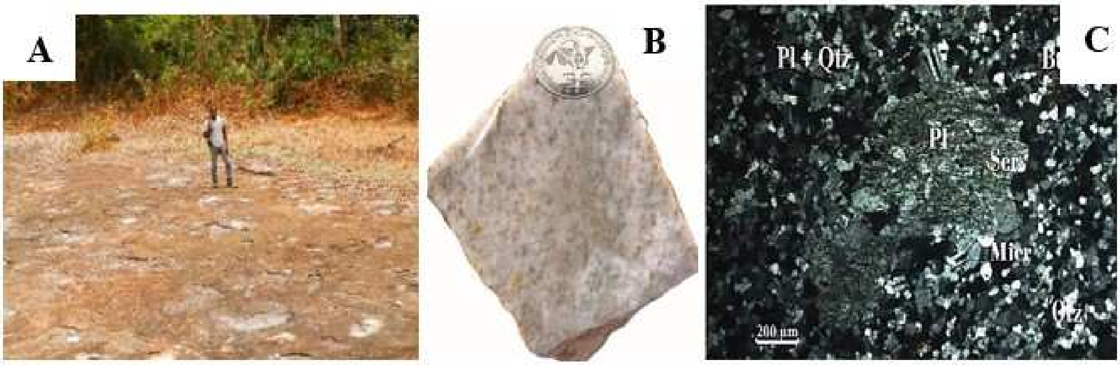

Figure 6. *Macroscopic and microscopic aspects of aplite from Logbakro (Logba03) Bt: biotite, Micro: microcline, Ser: sericite, Pl: plagioclase, Qtz: quartz.*

4.1.2. Geochemical Study

This study aims to provide additional information on the characterization of the granitoids of the study site, the origin of the parent magma, as well as the mode of emplacement, in order to understand the early evolution of the continental crust. Geochemical character and nomenclature.

The total chemical concentrations of major elements in the rock samples are given in Table 2. The analysis of the major elements shows a high composition of SiO_2 (64.76 -75.50%) and high contents of Al_2O_3 (13.90 and 15.51%). The concentrations of CaO (0.72-3.48%), TiO_2 (0.03 - 0.70%), P_2O_5 (0.01- 0.23%) and MgO (0.10 - 2.11%) are very low.

Table 1. *Petrographic characteristics of the various facies of the sillon.*

	Granodiorite	Biotite granite	Muscovite leucogranite dominant	Biotite leucogranite dominant	Aplite
Outcrop type	slab or block, enclave	Slab or large block	Block, sill, slab	slab or block,	Slab or block, lode and enclave
Colour	Mesocrate	Leucocrate to mesocrate	Leucocrate	Leucocrate	leucocrate
weathering	Weakly altered	Weakly altered	Weakly altered	Altered on some outcrops	Weakly altered
Texture	Medium grained	Fine to medium grained	Medium to coarse grained	Medium to coarse grained	Fine grained
Primary minerals	Bt, Plag, Qtz, Amp	Plag, Qtz, Bt, Mus, Flds-K	Qtz, Plag, Mus, Flds-K, Bt	Qtz, Plag, Bt, Flds-K, Mus	
Accessory minerals	Chl-Ser-Ep	Chl-Ep-Ser	Chl-Ep-Ser, Gt-Ap-Tour	Chl-Ep-Ser	Chl-Ep

Bt: biotite, Plag: plagioclase, Qtz: quartz, Amp: amphibole, Flds-K: feldspar-K, Chl: chlorite, Ser: sericite, Ep: epidote, Gt: grenat, Ap: apatite, Tour: tourmaline.

Alkaline contents (Na_2O+K_2O) are between 6.01 and 9.69%, lower than those of Al_2O_3, which shows the very aluminous character of these rocks. The Loss On Ignition (LOI), which represents the degree of alteration and the amount of water in the rocks, is very low except for the granodiorite sampled at Abokouamekro and the biotite granite sampled at Bonikro which have values of 0.68% and 1.28% respectively. The degree of alteration can also be assessed using the A-CN-K ternary diagram of researches with $A=Al_2O_3$, $CN=CaO^*+Na_2O$ and $K=K_2O$ (Figure 7A) [17, 18].

All the granitoids studied have AIC values generally below 60 with the exception of the Bonikro biotite granite (boni) which has an AIC value above 60, hence the low weathering in the rocks sampled within the study area. The samples plotted in the diagram (Na_2O+K_2O vs SiO_2) are mainly distributed in the granite field except for samples Kak01 and Abo03 which are found in the granodiorite field (Figure 7B) [15]. In the Ab-An-Or (albite-anorthite-orthose) ternary diagram of O'Connor, J. T. using normative feldspar values calculated from the CIPW standard (Figure 8A), sample Kak01 is at the tonalite-granodiorite boundary, while samples Abo03 show rather a trondhjemitic character, Moreover, the biotite leucogranite (Logb01) is found in the granodiorite field and the microgranite (Attie01) is at the granite-granodiorite limit, and finally all the other samples are located in the granite field [19]. As mentioned above the very aluminous character of the granitoids, the alumina saturation index (Al_2O_3/ ($CaO+Na_2O+K_2O$) shows values above unity (A/CNK=1.05 to 1.2) hence the peraluminous character. In the diagram modified by B. W. Chappell and J. R. White, the granodiorites of Kakoubroukro and Abokouamékro (Kak01 and Abo03) correspond to granites of igneous origin (type I) [2, 24]. The Logbakro biotite leucogranite (logba02) shows more of an S-type (supracrustal) composition, the I-S discrimination line in the diagram groups the other granites in the I-S field (Figure 8B) [24].

Table 2. *Chemical composition of granitoids of the central of the Fettekro sillon.*

ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
SiO_2	64,78	73,5	70,24	74,55	70,14	73,35	74,7	69,78	71,38	72,6	72,61	70,24	73,2	74,55	73,95	73,55	64,58
Al_2O_3	14,6	13,61	15,16	14,35	15,25	13,94	14,23	15,1	14,95	13,85	14,5	15,27	15,25	14,15	14,54	13,76	14,1
Fe_2O_3	6,32	2,4	2,4	0,88	2,5	2,29	0,91	2,8	2,1	1,65	1,79	2,4	1,5	0,98	0,98	2,23	6,25
CaO	4,5	1,3	1,24	0,81	2,24	1,3	0,75	2,24	2,55	0,81	0,91	1,24	2,9	0,99	0,77	1,25	3,64
MgO	2,11	0,56	0,57	0,1	0,77	0,7	0,1	0,57	0,49	0,3	0,3	0,57	0,73	0,1	0,1	0,71	2,25
Na_2O	3,92	3,37	3,51	4,47	3,91	4,1	4,5	3,9	3,78	3,98	3,98	3,51	3,15	4,25	4,65	4,2	4,9
K_2O	2,1	4,72	6,08	4,35	4,18	3,94	4,33	4,18	3,45	5,15	5,24	6,08	2,9	4,43	4,35	3,91	2,41
MnO	0,1	0,06	0,04	0,05	0,04	0,04	0,05	0,04	0,03	0,02	0,02	0,04	0,04	0,05	0,05	0,04	0,2
TiO_2	0,7	0,21	0,4	0,04	0,3	0,2	0,03	0,4	0,64	0,25	0,27	0,3	0,2	0,05	0,04	0,21	0,67
P_2O_5	0,101	0,12	0,21	0,015	0,21	0,06	0,01	0,21	0,23	0,09	0,09	0,19	0,06	0,01	0,01	0,04	0,09
LOI	0,66	0,14	0,13	0,15	0,21	0,05	0,09	0,26	0,3	1,28	0,28	0,14	0,06	0,2	0,16	0,06	0,68
Total	99,34	99,85	99,85	99,615	99,54	99,92	99,61	99,22	99,6	98,7	99,71	99,84	99,93	99,56	99,44	99,9	99,11
A/CNK	0,86	1,05	1,04	1,06	1,01	1,04	1,05	1,01	1,02	1,02	1,05	1,05	1,12	1,04	1,06	1,03	0,82
A/NK	1,67	1,28	1,23	1,19	1,39	1,27	1,18	1,38	1,50	1,14	1,19	1,24	1,83	1,20	1,18	1,23	1,32
FeOt	5,41	2,12	2,12	0,79	2,21	2,02	0,82	2,48	1,86	1,48	1,59	2,12	1,33	0,88	0,88	1,97	5,37
CIA	58	54	55	56	56	51	51	56	58	64	56	55	50	56	55	50	61

1: Kak01; 2: Kak02; 3: kak03; 4: kak04; 5: gour01; 6: gour02; 7: gour03; 8: attie01; 9: attie02; 10: boni; 11: ada; 12: logba01; 13: logba02; 14: logba03; 15: abo01; 16: abo02; 17: abo03

Kak: kakoubroukro; gour: gourminankro; attié: attiegouakro; boni: bonikro; logba: logbakro; abo: abokouamékro.

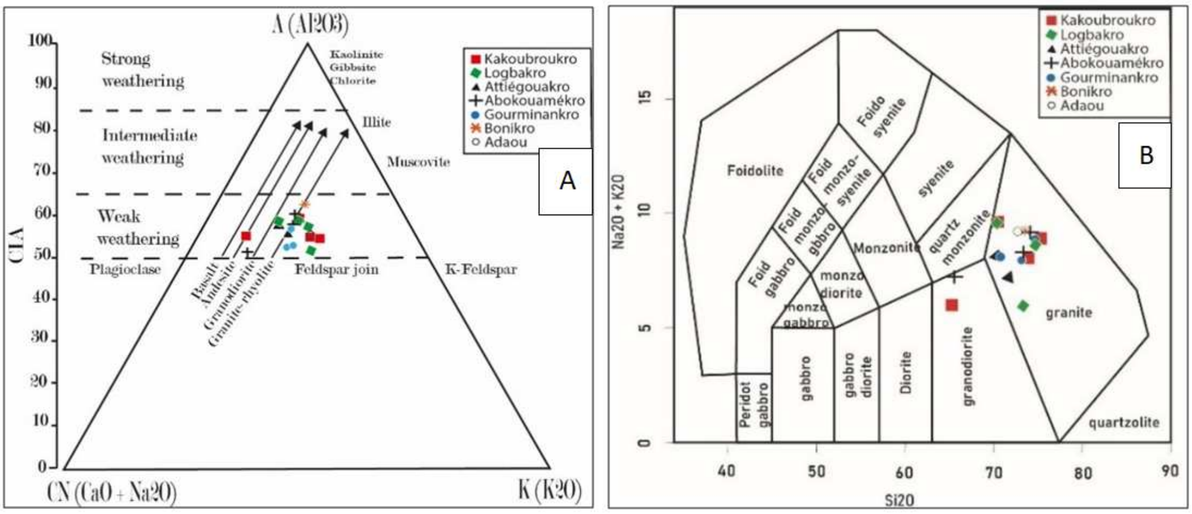

Figure 7. *(A) A-CN-K and CIA ternary diagrams of Nesbitt & Young (1982, 1984) applied to the granitoids of the central part of the fettekro trench; (B) Classification and nomenclature diagram of Middlemost, 1994 (TAS SiO_2 vs Na_2O+K2O) applied to the granitoids of the central part of the fettekro sillon.*

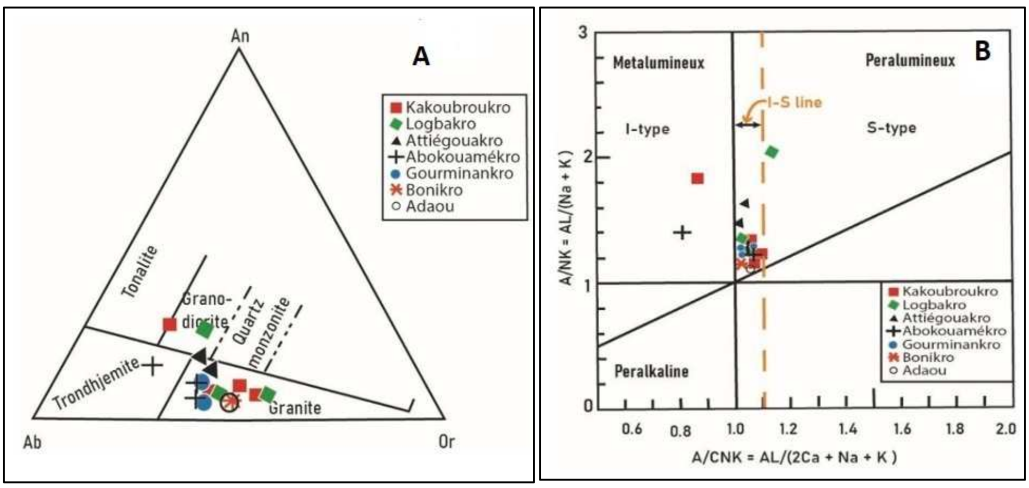

Figure 8. *(A): Ab-An-Or ternary diagram with Ab (Albite)-An (Anorthite)-Or (Orthose) by O'Connor (1965). (B) Shand's A/CNK vs A/NK diagram modified by Chappell and White applied to granitoids (2001). The discrimination line (orange dashed line) for granitoids is based on studies by Maniar and Piccoli (1989).*

4.2. Discussion

The granitic pluton of the central part of the Fettekro volcano-sedimentary sillon shows several facies, namely: granodiorite, biotite granite, dominant biotite and muscovite leucogranite and aplitic granite. This variety of facies implies several petrological processes (partial melting-crustal contamination-fractional crystallization), and therefore several magmatic episodes [20]. The minerals that characterize these granitoids are mainly composed of: quartz, plagioclase, biotite, muscovite, potassium feldspars, and opaque minerals. Granodiorite is characterized by a richness in ferromagnesian minerals (biotite-amphibole), a gritty texture with medium grains and a mineral deformation associated with a ribboning which gives it a migmatitic character. Biotite granite is characterized by an abundance of biotite and a micrograined to grainy texture. Two-mica granite is characterized by a high proportion of biotite to muscovite and vice versa with the presence of tourmaline and garnet (2 to 5%), the texture is grainy with medium to coarse grains. Aplitic granite is characterized by its very fine texture and biotite and feldspar minerals oriented in the birimal direction (NNE-SW). The ribboning observed within the granodiorites results from the segregation between the granitic neosome and the granodioritic paleosome discussed in the work of Dago. A. G. B on the Daloa batholith and oseph B. K., Nicaise K. A., Roland K. B. & Yacouba C. on the Issia granitoids [5, 6, 12].

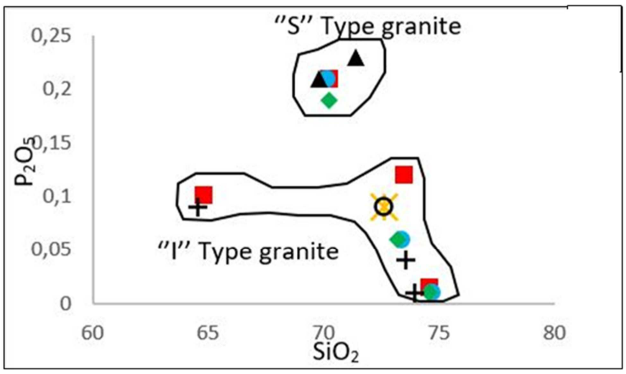

Figure 9. *P_2O_5 vs SiO_2 diagram of Chappell (1999, 2001) discriminating S and I type granites.*

The geochemical analysis of the granitoids in the central part of the Fettêkro Trench indicates a fairly low degree of CIA alteration overall, which corroborates the studies carried out by Ouattara, G. on the Ferkessedougou batholith, by Dago. A. G. B. and Joseph B. K., Nicaise K. A., Roland K. B. & Yacouba C. [5, 12, 21]. The majority of the granitoids studied (biotite granite, leucogranite and aplite) show high silica contents (69 < SiO_2> 74) and a richness in alkaline feldspar which gives them a peraluminous character (figure 8D), the presence of minerals such as: muscovite, tourmaline and garnet as well as numerous pegmatite veins in these rocks suggests a crustal origin therefore of S [12]. These arguments are contrary to those of [26], who believes that the presence of garnet, sillimanite, allanite and zircons in granites is characteristic of a magmatic origin (type I) and not of a sedimentary origin (type S). However, the diagram (P_2O_5 vs SiO_2) of B. Chappell. W. distinguishes two origins for the granitoids of the central part of the Toumodi-Fettêkro sillon (figure 9) [3]. Type S is rich in P_2O_5 while type I is poor in P_2O_5.

5. Conclusion

The granitoids of the central part of the Fettekro volcano-sedimentary sillon consist of granites, granodiorites, aplitic granites and leucogranites. The granites and leucogranites are distinguished by texture and grain size: biotite granite, biotite microgranite, biotite dominant leucogranite and muscovite dominant leucogranite.

Geochemical data show a low alteration rate in these rocks and a predominantly peraluminous character. The biotite granites, leucogranites and aplite are thought to be derived from S-type granites, thus resulting from the melting of sediments in a collusive context, while the granodiorite is derived from igneous granites (type I) from the partial melting of ancient TTG rocks.

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