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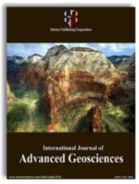
Research paper



Petrogenesis of metaluminous and peraluminous granitoids from Garga-Sarali zone : evidence of I- and S-type sources (central African fold belt in Cameroon)

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Abstract

The Garga-Sarali granitoids outcrop from a metamorphic basement in the central-eastern part of the Central Cameroonian Domain of the Central African fold belt in Cameroon, and are petrographically very complex. They can be divided into two types : (1) Granodiorites of metaluminous type-I, with a fine-grained porphyritic variant texture, consisting of quartrz + orthoclase + microcline + plagioclase + biotite + zircon + oxides ± apatite; (2) and two-mica granites of hyper-aluminous type-S, with a grainy texture, consisting of the same quartzo + k-feldspars + biotite + cordierite ± apatite. These formations both belong to a calc-alkaline-subalkaline, hyper-potassic to shoshonitic signature, and to the tectonic domains of volcanic arc granites. Their emplacement is intimately linked to a crustal parent magma (metagrauwackes and metabsalt-tonalites) that imbibed through the openings in the post-orogenic pan-African lithospheric constraints. Their La/Yb ratio, with (La/Sm)n ranging from 2.18-5.75 ppm, reflects their richness in LREE, and the average Eu/Eu*=0.666 ppm suggests that the residual magma was supersaturated with silica.

Keywords: *Petrography; Petrogenesis; Granodiorites; Two-Mica Granites; Garga-Sarali.*

1. Introduction

The Garga-Sarali granitoids belong to the Pan-African Central African Chain (Central African fold belt) and outcrop in slabs and multivaried blocks (fig. 1). Previous researches carried out in this area, such as the Magnetic Susceptibility Anisotropy (MSA) (Kankeu et al., 2006) and the geochemistry study of the Garga-Sarali granitoids (Daama et al., 2020), were not focused on the petrogenesis of these formations. The aim of this study is to provide a detailed petrographic and petrogenetic description of these granitoids, in order to contribute to improving and extending the knowledge available on the plutonic formations of the Pan-African Central African Chain.

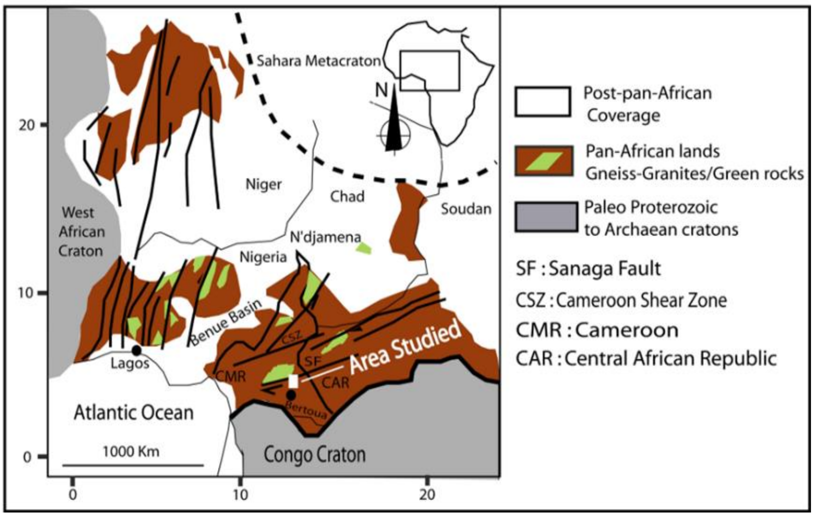

Fig. 1: Post Pan-African and Pan-African in Central Africa, (After Ferré Et Al., 1996 ; Toteu Et Al., 2004).

2. Geological setting

The studied area consists mainly of migmatites and gneisses (Ndokayo orthogneiss), schists of the presumed Lom schist belt, meta-leucogranites, metagranodiorites, porphyroid granites and fine-grained Kongolo granites (Kankeu et al., 2006). The porphyritic and fine-grained granites contain schist enclaves (Daama et al., 2020) that display crenulation schistosity and folds. These structural features are controlled by the Sanaga ENE-WSW-trending fault (Ngako et al., 1991). A major antiform has been indicated, parallel to the Sanaga fault. These structures are intimately linked and interpreted as the products of transpression (Kankeu et al, 2009). Late-tectonic granites (including those of Garga-Sarali) are emplaced during strike-slip deformation, characterised by subhorizontal lineations that reflect the magma factory.

3. Methodology and analytical methods

26 thin sections were carried out in the laboratory of the "Institut de Recherches Géologiques et Minières (IRGM)" in Yaoundé. The computer-assisted microscope was used in the Mineral Processing Laboratory (LTM) at IRGM to identify and describe the various parageneses. The analytical methods of ICP-ES and ICP-MS were used at Veritas laboratory in Vancouver (Canada), to perform representative analysis of major and trace elements on seventeen samples. Thus, this geochemical analysis was done using the pulp. Whole-rock analyses were done by Inductively Coupled Plasma-Atomic Emission (ICP-AES) for major elements and by Inductively Coupled Plasma Mass Spectrometry (ICP-MS) for trace elements. The samples were pulverized to obtain a homogeneous sample, out of which 50–60 g were obtained for the analyses. 0.1 g of rock powder was fused with 1.5 g of $LiBO_2$ and then dissolved in 100 mm^3 of 5% HNO_3. Loss on ignition (LOI) was determined by the weight difference after ignition at 1025 °C. Some samples were crushed to extract cordierite megcaryst (figure 2). Various standards were used, and data quality assurance was verified by running these standards between samples as unknowns.

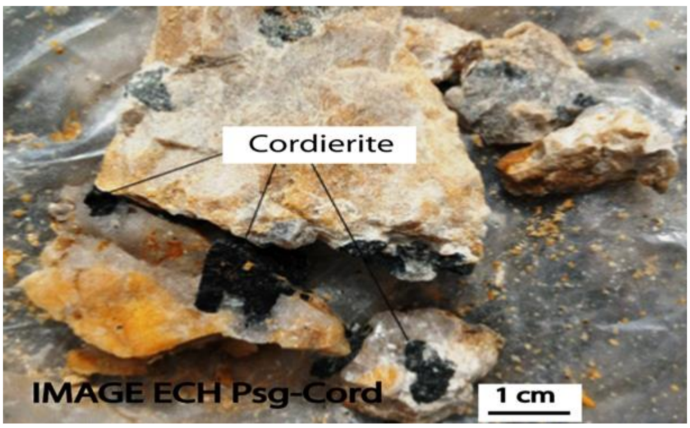

Fig. 2: Cordierite Megacrystals in Two Mica Granites.

4. Petrography

The Garga-Sarali granitoids outcrop from a gneissic and schist basement (fig.6) and can be classified into two main types: granodiorites and two-mica granites crossed by cordierite pegmatites. Granodiorites and two-mica granites belong respectively to metaluminous and peraluminous domain.

4.1. Granodiorites (metaluminous granitoids)

Granodiorites are found precisely in Ndanga-Gadima, Kongolo and western edge of Kongolo sectors.

- The Ndanga-Gadima (NG) type, (05°25'51"N; 14°02'27"E) outcrops in blocks (~5 m), slabs (~25 m) of medium-grained texture, they are whitish, mottled black, slightly altered, containing double schist enclaves. They consist of sub-hedral quartz (0.3—1.3mm, 20 vol.%), more or less embedded in feldspars and oxides; orthoclase (1—4mm, 15 vol.%), tabular and prismatic; compact spathic microcline (>3mm, 30%) with polysynthetic macle. Sub-hedral plagioclases, (>5mm, < 10 vol.%) with sharp rectilinear contours are present; Biotite (0.5-4 mm, 10 vol.%) crystals are skeletal lamellaes. Zircon is rare (<2%, <1mm) and occurs as a prismatic-rounded inclusion in quartz. Apatite is very small (<5 vol.%, <1µm), sub-hedral, and oxides (~ 8 vol.%) are seen as inclusions in K-feldspars.
- The Kongolo type, with a micro-grained texture (< 2 mm), outcrops (a, b), (05°23'33" N; 14°01'26"E), in blocks (≤5 m) and slabs (≤ 22 m). Its paragenesis differs from that of the Ndanga-Gadima type by the absence of apatite and plagioclase crystals.
- The porphyroid type on the western edge of Kongolo (05°22'50"N; 13°59'29"E) outcrops in the form of very large boulders (< 1 m) and slabs (12—30 m size). Their porphyritic texture consists of abundant orthoclase (<4mm, 45 vol.%), quartz (<2mm, 15—20 vol.%), biotite (30 vol.%), and oxides included in the quartzo-feldspathic matrix.

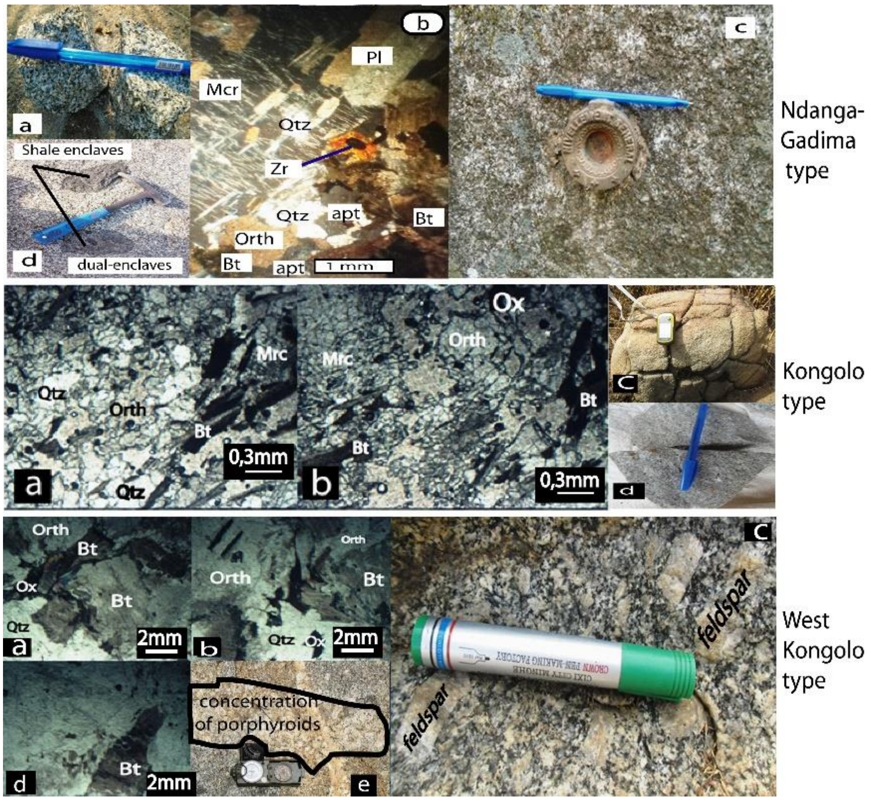

Fig. 3: Macroscopic and Microscopic Photographs of Granodiorites (Qtz = Quartz, Orth = Orthoclase, Mcr = Microcline, Pl = Plagioclase, Bt = Biotite, Zr = Zircon, Apt = Apatite, Ox = Oxide).

4.2. Two-mica granites (peraluminous granitoids)

Two-mica granites outcrop (05°19'34"N; 14°02'50"E) in form of blocks (~2 m), and slabs (~30 m) containing cordierite grains (fig. 4. h). These granites are crossed by cordierite-bearing pegmatites and have a slightly weathered appearance (fig. 4. f) with a grainy texture (fig. 4. g).

Its petrographic component consists with: sub-hedral quartz (0.3-1.3 mm, 20 vol.%) (fig. 4. b); prismatic orthoclase (2—6 mm, 25 vol.%) with traces of destabilization (fig. 4. c); subhedral microcline (>2mm, 10%), tabular, mottled, with an observable aspect of alteration (fig. 4. a); Muscovite forms huge large euhedral laminae (> 0.5 mm, 20 vol.%) and open cleavages filled with oxides and alkali feldspars. Biotite (0.2—3 mm, 10 vol.%) occurs in very elongated aggregates rich in oxide inclusions. Sub-hedral plagioclase (>1mm, vol. 5 vol.%), jointed with orthoclase and biotite, and showing polysynthetic macles (fig. 4. e, f); Cordierite (> 3 mm, 7 vol.%) are present in pseudo-hexagonal crystals (fig. 4. c, d). Apatite is tabular tending to hexagonal form (≤ 0.5mm, 3 vol.%); Oxides (≤ 0.3mm, 5 vol.%) are present.

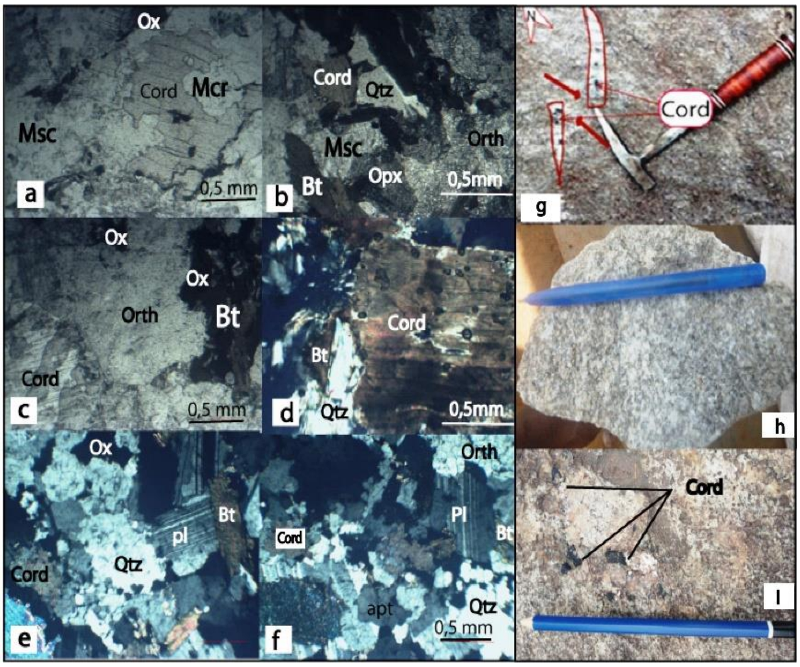

Fig. 4: Macroscopic and Microscopic Photographs of Two-Mica Granites. (Qtz = Quartz, Orth = Orthoclase, Mcr = Microcline, Pl = Plagioclase, Bt = Biotite, Apt = Apatite, Cord = Cordierite, Ox = Oxide.

4.3. Cordierite-bearing pegmatite

Cordierite-bearing pegmatites of Garga-Sarali oriented N65—80°E, are characterised by it texture and the occurrence of Quartz + Feldspar + Biotite + Muscovite + Cordierite (fig 5. b, c, d (fig.5. e, f). Crystals of quartz, feldspars, muscovite and biotite are subhedral and vary in size from 0.5 cm to 2 cm. Cordierite occurs as independent grains scattered in the pegmatitic matrix, usually in a certain alignment (fig. 5. a, e).

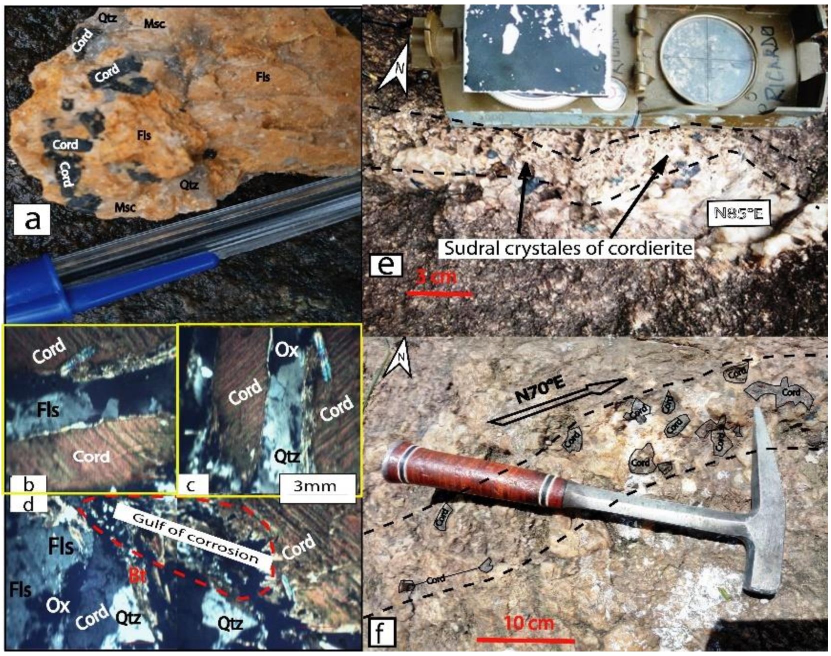

Fig. 5: Cordierite-Bearing Pegmatite.

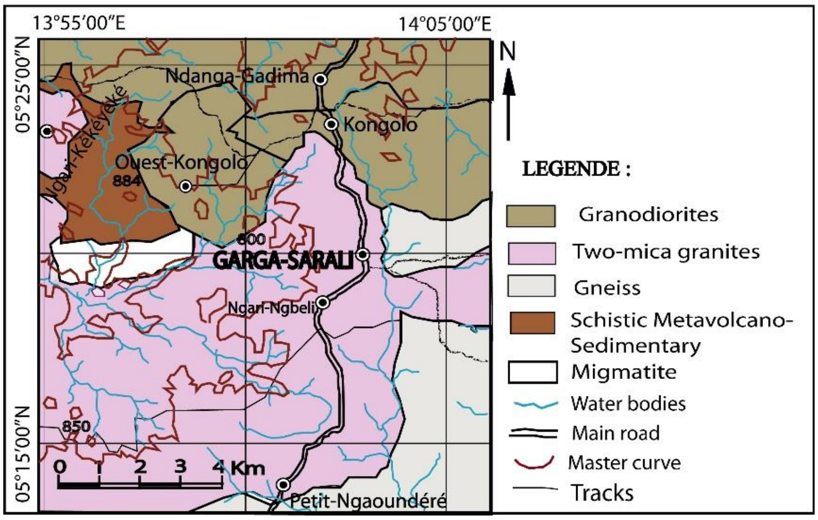

Fig. 6: Geological Map of the Studied Area of Garga Sarali.

5. Geochemical data and petrogenetic implications

5.1. Nomenclature of the studied rocks

All the Ndanga-Gadima, Kongolo and western Kongolo samples belong to a typically granodioritic end of the calc-alkaline series (Fig. 7.a), and those from the Garga-Sarali two-mica granites fall within the granite series. Discrimination of 10000Ga/Al as a function of Zr shows that all these samples fall within the field of type I & S granites.

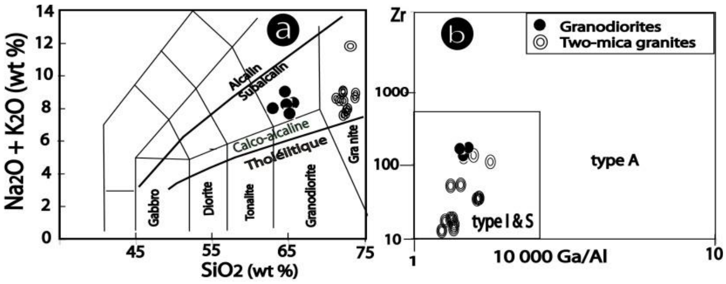

Fig. 7: Total Alkalinity Diagram (TAS) By Macdonald and Katsura (1964) (A); And Discrimination Diagram for Type A and Type I & S Granites by (Whalen Et Al., 1987) (B).

5.2. Nature of the magma source

Type-I granodiorites with metaluminous signature (fig. 8.a) are thought to have resulted from subcrustal partial melting of a mainly metabasalt-tonalite (fig. 8.b). Type-S peraluminous granite with two micas (fig. 8. a) is thought to have resulted from supra-crustal partial melting of an essentially metagrauwackes compound (fig. 8. b).

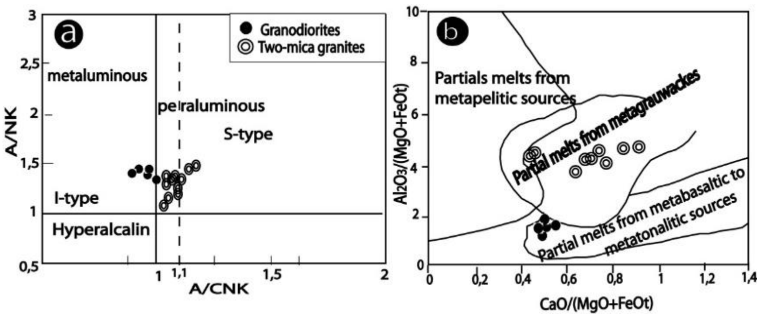

Fig. 8: A/CNK vs A/NK Diagram According to (Shand Et Al., 1943), and Cao/(Mgo+Feot) vs Al_2O_3/(Mgo+Feot) According to the Dehydration Experiment of (Wolf and Wyllie, 1994).

5.3. Tectonic field setting

The Tecto-discriminant of Rb (ppm) versus Y+Nb (fig. 9. a), shows the exclusive positioning of all the samples in the field of volcanic arc granites (VAG). The diagram (fig. 9. b) of Nb/Zr (normalised to the primitive mantle (McDonough and Sun, 1995) as a function of Zr (b) shows that all the samples are located in the field of collisional rocks.

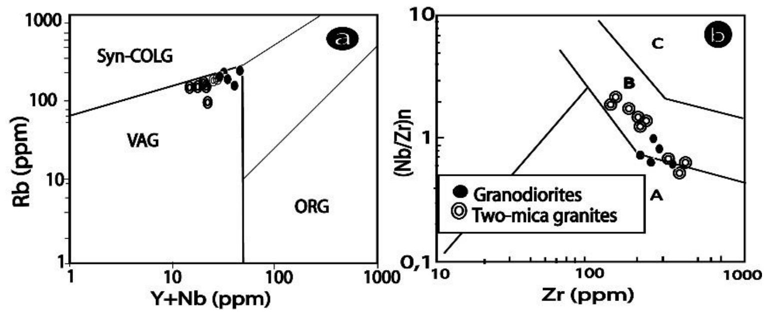

Fig. 9: Tecto-Discrimination of Rb as A Function of (Y + Nb) (A) (Pearce Et Al., 1984); and Diagram of (Nb/Zr)N as A Function of Zr (Thiéblemont Et Al., 1994) (B). A = Subduction Zone Magmatism Rocks; B = Collision Zone Rocks; C = Intraplate, Alkaline Rock; WPG = Intraplate Domain Granites; VAG = Volcanic Arc Granites; Syn-COLG = Syn-Collisional Granite; ORG: Oceanic Rift Granites.

5.4. Alkaline behaviour

The diagrams of figure 10 show that all the samples from granodiorites are trans-alkaline, i.e. sub-alkaline (a), and belong to the shoshonitic series (b), whereas those from two-mica granites split between the trans-alkaline and calco-alkaline field (a), and are hyper-potassic to shoshonitic (b).

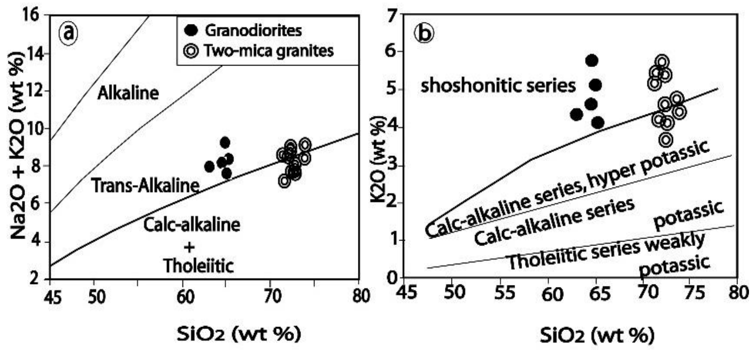

Fig. 10: Na_2O+K_2O Versus Sio_2 Diagram from Middlemost (1997) (A); and K_2O Versus Sio_2 Evolution Diagram (Maître Et Al., 1989).

6. Discussion

6.1. Occurrence model of studied rocks

The size of the outcrops, which for the most part is decametric, is explained by the width of the lithospheric fissures left by the multiple faults during a major phase of pan-African cooling, according to the model in figure 11. The frank contact of these granites with the metamorphic host rock is evidence of a high temperature contrast, which would not have allowed the assimilation of the edge

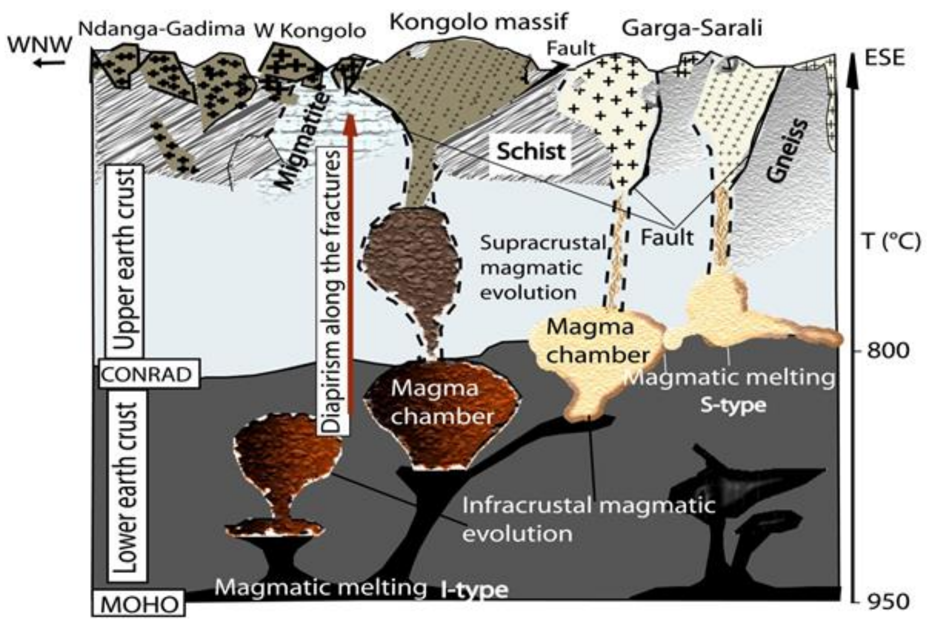

Fig. 11: Emplacement of Outcrops (Boulders, Slabs, Plutons) of the Garga-Sarali Granitoids Beside A Gneissic and Schist Basement (Modified After Haimeur Et Al., 2004).

6.2. Geodynamic context

The total alkali diagram (fig. 12a) indicates that the studied samples are granodiorites and granites from calc-alkaline setting, typically similar to other granitoids of the Pan-African litho-structural domain (Toteu et al., 2004), in particular the granitoids of the Mbip Tcholliré massif (Nomo et al., 2017) which share the same tectonic context (fig.12. a). And especially those of Mbaibokoum (Naimou et al., 2014), which have a virtually identical calc-alkaline footprint (fig.12. b). This suggests magmatic proximity to a subducted crust, where products such as metagrauwackes would have undergone dehydration according to the experiments of Shand et al. (1943), leading to the formation of the S-type granites similar to those from Garga-Sarali.

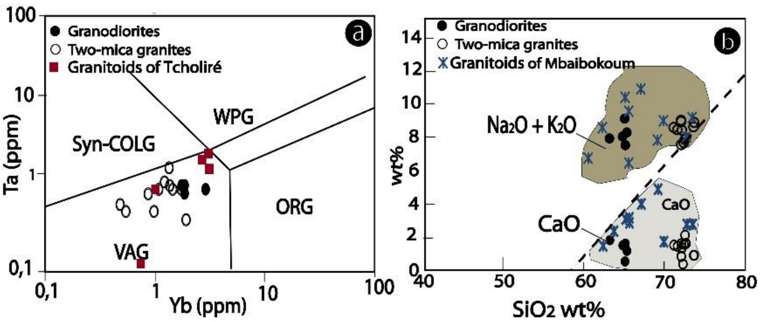

Fig. 12: Tecto-Discriminant Diagram Yb vs Ta (Pearce Et Al., 1984), and Sio_2 vs (Na_2O+K_2O) and Cao Correlating Samples from the Granitoids of Garga-Sarali and Surrounding Compared to Those from the Mbip Massif of Tcholiré (Nomo Et Al., 2017) (A). and Diagram of Correlating Samples of Granites from Garga-Sarali and Environs, with Those from Mbaibokoum (Naimou Et Al., 2014) (B).

6.3. Inferences concerning crystallisation

Figure 13 shows the evolution of the major and trace elements in the samples as a function of SiO_2 (Harker, 1909). Ferromagnesium (Fe_2O_3, MgO), CaO, TiO_2, MnO and P_2O_5 show decreasing trends, which are respectively compatible with fractional of biotite, plagioclase, oxides and apatite crystals. The evolution of Al_2O_3 shows sub-vertical decreases in their content during the differentiation of the samples, which would be in the distinctive agreement with fractional crystallisation of aluminous minerals such as muscovite and cordierite, and that of K_2O bears witness to the growth of potassic feldspars (orthose, microcline) in the migmatitic liquid. Trace elements also show similar patterns of decrease to those of the major elements, with the exception of Ta, which is a highly incompatible element that shows an increasing trend during the differentiation of these rocks. The very marked fall in zirconium could explain the crystallisation of zircon observed in the Granodiorites.

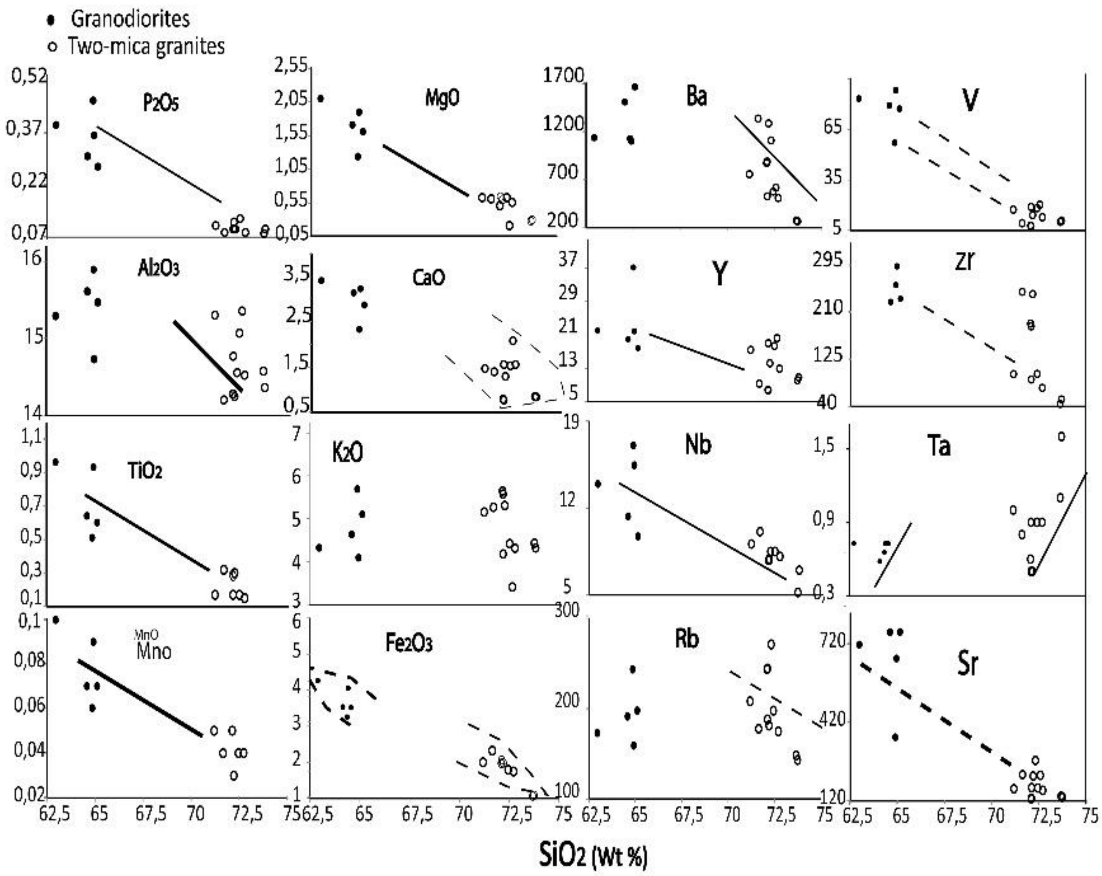

Fig. 14: Harker Diagram (1909) of Certain Major and Trace Elements as A Function of Silica (Sio2).

Cordierite is frequently found in metamorphic rocks, and its presence in these two-mica granites is highly suggestive of the magmatic materials and particular mechanisms that controlled its formation. According to the dehydration experiment of Wolf and Wyllie, (1994), these rocks were derived from a metagrauwacke protolith (fig. 8b). As it happens, the latter is a rock derived from the earlier prograde metamorphism of micaceous and plagioclastic sandstones (Nédélec and Bouchez, 2011), which is a prerequisite that supports the presence of an aluminous mineral such as cordierite in these formations. In addition the work of Vielzeuf and Montel, (1994) on the incongruent melting of metagrauwacke at temperature $750 \leq T°C \leq 1000$ and $P° \leq 800MPa$, calibrates that the reaction biotite + quartz + sillimanite ± plagioclase = granitic liquid + cordierite at $P° \leq 500Mpa$. This relationship shows that all the ingredients were present for the cordierite to fractionate in the magmatic liquid, and not to have come from elsewhere (from the host rock as an enclave). Its subhedral crystalline form reinforcing this idea.
However, its absence in biotite granodiorites is not without surprise, since it is thought to be the result of the partial melting of metabasalt-tonalites (see fig. 8), which are poor in aluminous compounds and richer in ferromagnesians. Their ratio A/CNK < 1 shows that they are metaluminous type-I (fig. 8a), and their ratio A/NK < 1 fundamentally distinguishes them from silica-rich hyper-alkaline type A granites (fig. 7b) (Loiselle and Wones, 1979). Two-mica granites, on the other hand, are of Type-S, showing high alumina saturation (A/CNK >1) linked to the presence of S aluminium-hungry minerals (Chapell and White 1974), mainly cordierite. We can also assume that its parent magma was of relatively low temperature and hydrated (Shand et al., 1943), which would have further amplified this alumina enrichment. According to Jonin (1981), cordierite granitoids, because they are hot and dry, have a higher ascent capacity than muscovite-only granitoids, which are cold and wet, which may explain their higher rate of crystallisation at the outcrop surface in our case (see fig 4. i, g; fig 5. e, f).

6.4. REE reports

The variation in the La/Yb ratio shows a scattered and progressive decrease with increasing SiO_2 values (fig. 18.aThe disparity of the samples around the decreasing bilinear (τ) would suggest a re-equilibration of these minerals with residual magmatic fluid. Their high content of heavy rare earths (Daama et al., 2020) could be due to the presence of this fluid at the time of crystallisation, which would have led to vein pockets in the cordierite-bearing pegmatites. The diagram, Eu/Eu*= (0.666) on average vs SiO_2 has a sub-vertical increasing trend, which would testify to the overgrowth of feldspars in the magmatic fluid, hence perhaps the evidence of abundance of feldspars in these rocks. While for advanced hyper-silicic rocks such as rhyolite, the values (0.65—0.24) in this ratio would explain the supersaturation of the silicic magmatic residue (Mbowou et al., 2012), those in our case (granitic rocks) would confirm this hypothesis. The decrease in the Eu/Eu* ratio as a function of SiO_2 clearly reflects this supersaturation of the silicic residual magma. This would logically be accompanied by a decrease in the Eu^{3+}/Eu^{2+} ratio, as we move from an oxidising environment to a silicic environment.

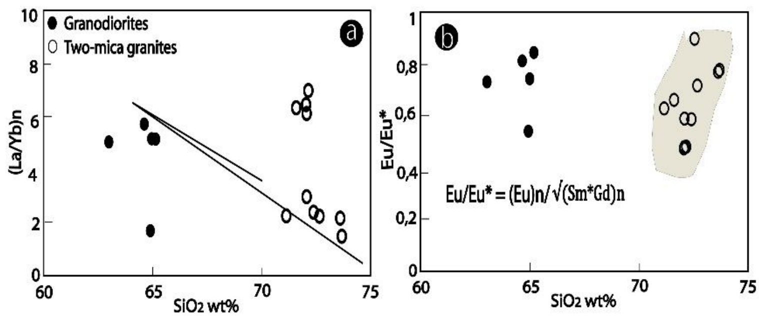

Fig. 14: Diagram of Variations in the La/Yb Ratio (A) and the Eu*/Eu Ratio (B) as A Function of Sio2

7. Conclusion

Our study of the granitoids of Garga-Sarali and the surrounding area has led to a number of interpretations and discussions aimed at understanding the petro-magmatic mechanisms that have contributed to their specific characteristics. These formations are of two types, granodiorites and two-mica granites. Their chemical nature is calc-alkaline and they are of type-I and type-S respectively. Their emplacement is thought to be linked to a crustal magma that imbibed through the openings in the pan-African post-orogenic lithospheric constraints. Correlational studies of the Garga-Sarali granitoids have shown a high degree of petrogenetic concordance with certain granitoids of the Central Pan-African African Chain (CPAC). Hyper-aluminous granites often show affinities for the mineralisation of certain rare metals (Nédelec and Bouchez, 2010), so it would be judicious for this work to continue with mineralogical analysis of these formations.

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