

Petrogenesis and Geochemical Characterization of the Granitoids of the Magba Shear Zone West Cameroon Central Africa

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Abstract

Magba granitoids are made up of granites, orthogneiss, migmatites, metagabbro, mafic dykes and mylonites with respectively porphyritic, porphyroblastic, grano-lepido-porphyroblastic, and cataclastic texture. Mafic dykes and metagabbro occur as intrusives into the mylonitic and granitic rocks. Magba rocks were subjected to whole rock geochemistry analyses and results show that those rocks have the chemical composition of gabbro, monzodiorite, monzonite syenite, quartz-monzonite, granodiorite and diorite. The rocks are metaluminous, display high-K, calc-alkaline to shoshonitic affinities and plot on the field of volcanic arc granites and are formed by differentiation of I-type magma. They are largely situated within the syn-collision to within plate fields, show a subduction—to collision-related magmatism, and suggest their emplacement during the syn—to post-collisional phase of the Pan-African orogeny.

Keywords

Magba, Granitoids, Metaluminous, Syn-Collision

1. Introduction

Magba area is situated at the junction of the Cameroon Central Shear Zone (CCSZ), the Adamawa Fault (AF) and the Tibati-Banyo Fault (TBF) in Cameroon (**Figure 1**). The CCSZ is a major lineament of the Pan-African

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orogeny of Central Africa; however, the tectonic significance of widespread Pan-African structures at a regional scale is a matter of debate [1] [2]. The divergent views include the operation of transpressive tectonics during the Pan-African orogeny in the central Cameroon. [2] have suggested an early convergence and compression (D_1) in the eastern Cameroon, followed by further crustal compression with peak metamorphism (D_2) and a late Pan-African transpression (D_3).

The disposition of Magba area at the junction of shear zones is very important in understanding the CCSZ kinematic, and the emplacement conditions of these rocks. Very few geological investigations have been carried out earlier on the Magba area [3]-[5]. Hence, the current understanding on the petrography, geochemistry and tectonic evolution of the Magba area is very limited. Herewith, to fill this gap we are presenting detailed petrography and geochemistry for Magba granitoids to provide much insight in understanding the nature of these rocks, and their conditions of emplacement.

2. Regional Geological Setting

2.1. Regional Geology

The Precambrian basement complex of Cameroon consists of two major lithostructural units; the Congo Craton (CC) and the Central African Fold Belt (CAFB) (Figure 1). These rocks record the crustal evolution of the region from the Mesoarchaeon to Neoproterozoic [6] [7]. The CAFB is defined by a system of NE-trending faults comprising Tchollire-Banyo Fault (TBF), Adamawa Fault (AF), Sanaga Fault (SF) and Kribi-Campo Fault (KCF).

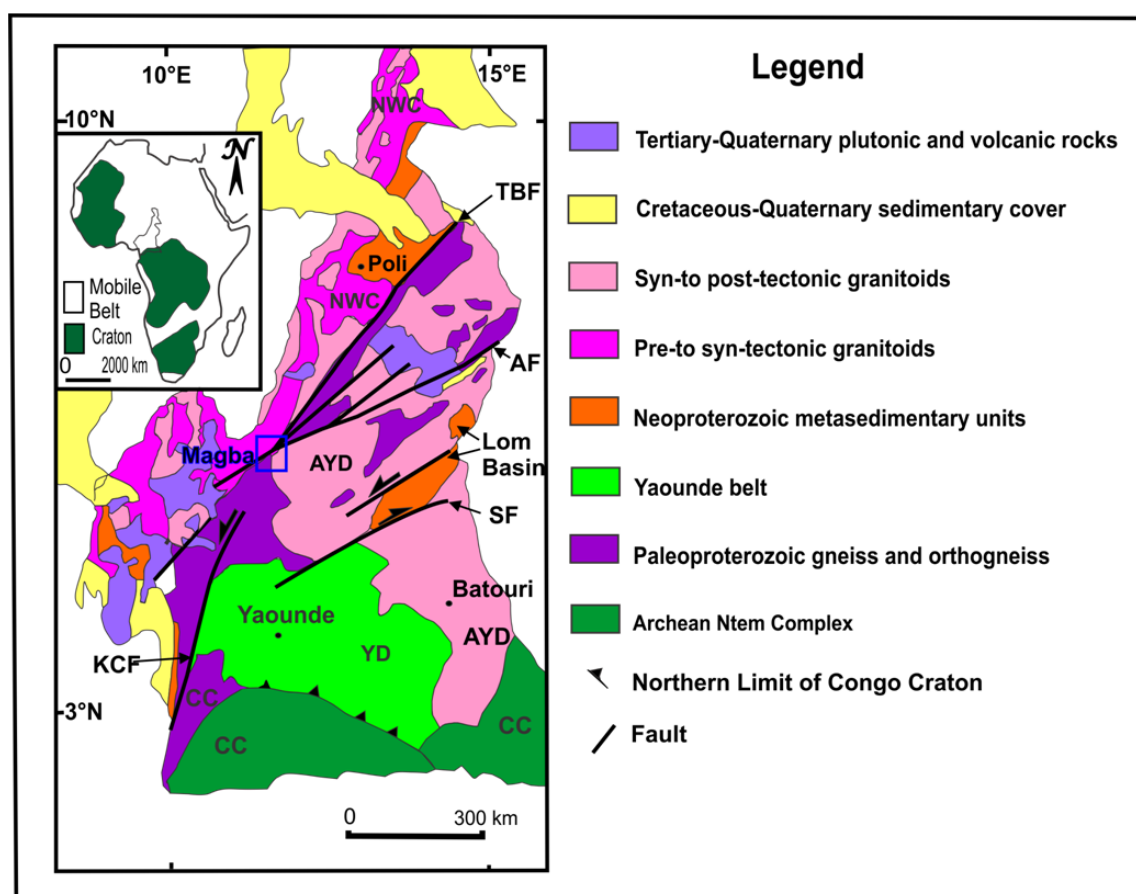


Figure 1. Geological map of Cameroon modified after Toteu *et al.* (2001). The Central African Shear Zone is defined by a system of NE-trending faults comprising Tchollire-Banyo Fault (TBF), Adamawa Fault (AF), Sanaga Fault (SF), and Kribi-Campo Fault (KCF). The inset is the map of the African continent, showing the location of Cameroon relative to the distribution of cratons and mobile belts.

2.1.1. The Congo Craton (CC)

The CC includes a well-preserved Archaean (Ntem Complex) and Palaeoproterozoic domains (Nyong Series) recording the Precambrian crust formation history of Cameroon [6] [8]. The Ntem Complex is predominantly made of Archaean rocks (3.1 - 2.5 Ga) that were partially reworked during the Palaeoproterozoic Transamazonian cycle [6] [9]-[12]. Greenstone belts though volumetrically less, form important litho units within this complex, and show intrusive relationships with the basement rocks. The Archean basement rocks include high grade charnockites and undifferentiated tonalite-trondhjemite-granite (TTG) suite of rocks [6] [11] [13] [14]. The Palaeoproterozoic Nyong Series crops out to the West and East of the Ntem Complex (**Figure 1**) [15]. It is part of the Palaeoproterozoic Transamazonian belt, which extends from Central Africa to northeastern Brazil [6] [16]-[18]. The Nyong Series consist mainly of high-grade gneissic rocks, including biotite-hornblende gneiss, charnockite, garnet-amphibole-pyroxenite and Banded Iron Formation (BIF). Pan-African intrusives cut across the Nyong Series rocks and include weakly metamorphosed diorite, granodiorite and syenite, in addition to post-tectonic dolerites at few locations [6] [18].

2.1.2. The Central African Fold Belt (CAFB)

The $\sim 600 \pm 70$ Ma CAFB is a major collisional belt that underlies the region from the West African Craton to East Africa [12] [19]. It extends in parts of Nigeria, Cameroon, Chad, Central African Republic and Sudan to Uganda in the further east [19]. According to their age, three lithological domains have been identified in the CAFB in Cameroon, namely the Adamawa-Yadé (AYD), Yaoundé and Northwestern Cameroon domains [12] [20].

The Adamawa-Yadé Domain [12] [20] is the largest domain of the CAFB in Cameroon, dominated by 640 - 610 Ma, syn- to late-collisional high-K calc-alkaline granitoids (**Figure 1**). These granitoids intrude high-grade gneisses that represent a Palaeoproterozoic basement, which was likely dismembered during the Pan-African assembly of western Gondwanaland [10] [12] [20]. [20] [21] classified the rocks of the AYD into three main groups, viz. a) Large supracrustal blocks of Palaeoproterozoic metasedimentary rocks and orthogneisses with assimilated Archaean crust similar to the Ntem Complex, b) 612 - 600 Ma, low- to medium-grade metasedimentary and metavolcaniclastic rocks, and c) 640 - 610 Ma syn- to late-tectonic granitoids of transitional composition and crustal origin [12].

The Yaoundé Domain consists of an extensive tectonic nappe that was thrust onto the CC during the Pan-African collision [6] [12] [20] [22]. This domain is analogous to the Gbayas and Sergipano nappes in Central African Republic and Brazil, respectively. Thrust slices of metasedimentary rocks with poorly constrained ages of ~ 626 Ma [21] are common in the Yaoundé Domain [6] [7] [12] suggested that the detrital material was derived from juvenile Palaeoproterozoic and Neoproterozoic sources in the southern part of the AYD, as well as from the Palaeoproterozoic Nyong Series in the CC.

The Northwestern Cameroon Domain is located to the west of the Tcholliré-Banyo Fault (TBF), along the western border of Cameroon and extends into eastern Nigeria. It includes a variety of rock types, namely a) medium- to high-grade schists and gneisses of the ~ 700 Ma Poli series, b) ~ 660 - 580 Ma calc-alkaline granitoids (diorite, granodiorite, and granite), c) anorogenic alkaline granitoids, and (d) low-grade sedimentary and volcanic basin sequences [12] [20]. It is generally believed that the CAFB was formed during the Neoproterozoic collision of the West African Craton with the Congo Craton [20]. [20] proposed a three-phase evolution, which began by the emplacement of calc-alkaline granitic rocks (670 - 660 Ma), followed by crustal thickening, high-grade metamorphism, calc-alkaline magmatism (640 - 610 Ma), and finally overprinted by post-collision nappe formation, sub-alkaline to alkaline magmatism (600 - 545 Ma) and molasse basin sedimentation.

2.2. Geology of Magba Region

The study area forms part of the Tikary plain, morphologically a transitional zone between the high western plateau and the Adamawa plateau, with an average elevation of 810 m and covers approximately 400 km² area. It is characterized by two major morphological units namely the plains, made of mylonites and metagabbro and the hills, made of granites, mylonites and migmatites [5]. The hills are elongated and oriented N40-45°E (**Figure 2**), the orientation being parallel to that of the Cameroon Volcanic Line [3] [4] [23]. The rock exposures are limited and confined to slopes and hilltops in lowlands and river beds. These rocks form part of the CCSZ and consist of migmatites, orthogneiss, mylonites, metagabbros and mafic dykes. Mylonites and granites have cross-cutting re-

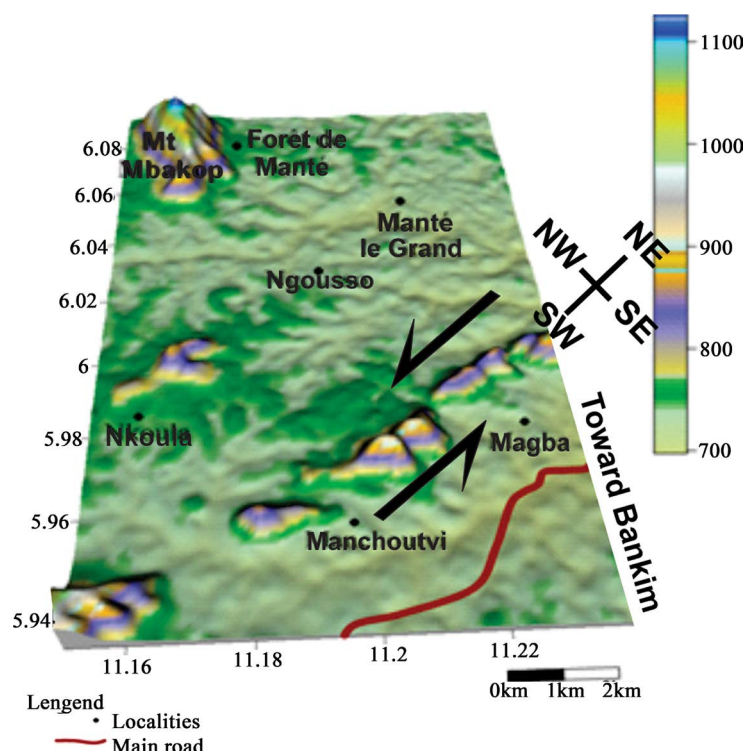


Figure 2. Digital model elevation (DME) of the study area showing the alignment of hills (NE-SW).

relationships with the intrusive younger mafic dykes and quartzo-feldspathic veins while orthogneisses and migmatites are intruded by amphibolitic enclaves. Compositional banding is noticed all through the migmatites, and characterized by 1) gneissosity with good compositional layering with the intrusions of aplite and pegmatite veins; and 2) a metatexitic banding marked by vein injections sub-parallel to the gneissic foliation, the whole unit is being stretched and reinforced by quartzo-feldspathic veins. Folded amphibolitic boudins are observed in the orthogneisses and migmatites, while the faults are mostly confined to mylonites.

3. Methodology

3.1. Field Methods

Geological fieldwork involved mapping and sample collection. Forty samples were collected, representing various lithologies of the study area. The structural elements of each tectonic event were documented wherever possible, and their orientation (strike and dip) were measured to relate with regional deformational events that define the structure and emplacement of the granitoids.

3.2. Laboratory Methods

Representative samples chosen for whole-rock geochemical analyses from the Coorg Block are devoid of any surface alteration or weathering. The bulk samples were initially reduced in a jaw crusher, and then manually fine powdered in agate mortars to avoid any contamination.

Major oxides were analyzed using a Phillips® MagiX PRO Model 2440 X-ray fluorescence (XRF) spectrometer provided with suitable software SUPER Q 3.0, was used for this study (Philips, Eindhoven, The Netherlands) at the CSIR-National Geophysical Research Institute, Hyderabad. The MagiX PRO is a sequential instrument with a single goniometer based measuring channel covering the complete elemental measurement range from F to U in the concentration range from 1.0 ppm to % level, determined in vacuum media. The instrument is microprocessor controlled for maximum flexibility and consists of an end window

X-ray tube with an Rh anode and a maximum voltage/current of 60 kV/125mA at a maximum power level of 4 KW. Pressed pellets of the representative samples and geochemical reference materials were prepared sepa-

rately and loaded into XRF for analysis. Preparation of pressed pellets involved weighing two grams of finely powdered (~200 mesh ASTM) sample/standard in collapsible aluminium cups [24] filled at the bottom with ~2.5 g of boric acid, which was later pressed under a hydraulic pressure of 25 t to obtain the pellet. International rock reference materials from the USGS, Geological Survey of Japan, Natural Resources Canada, International Working Groups (France) and National Geophysical Research Institute (India) were used to prepare calibration curves for major elements, and to check the accuracy of analytical data. Calibration graphs were obtained with the SUPER Q 3.0 analytical software issued by the instrument manufacturer and using linear regression of the net intensities versus concentrations of more than ten certified reference materials. The precision and accuracy of the analysis was <2% RSD for almost all the major oxides.

For trace elements including rare earth (REE) and high field strength elements (HFSE), the homogenized sample powder was dissolved in reagent grade HF: HNO₃ acid mixture in Savillex® screw top vessels. A test portion (0.05 g) of sample was added to 25 ml Savillex Teflon pressure decomposition vessels. To each sample, 10 ml of an acid mixture (containing 7:3:2 HF-HNO₃-HCl) was added. Subsequently, 5 ml of 1 ng/ml ¹⁰³Rh solution was added as an internal standard to each Savillex vessel. After thorough swirling, the vessels were tightly closed and kept on a hot plate at ~140°C for 48 h. Following this, the vessels were opened and the contents were evaporated at 200°C to near dryness with a few drops of HClO₄ to ensure complete removal of HF and HCl from the mixture. The remaining residues were dissolved by adding 10 ml of 1:1 HNO₃ and the volume was made to 250 ml with Milli Q® de-ionized water (18 MΩ), and the solution was stored finally in HDPE bottles. Matrix matching certified reference materials JG-2, JG-3, JB-2 from Geological Survey of Japan and G-1A, G-2 from USGS along with couple of procedural blanks were also prepared with the sample batch by adopting the same protocol described above to negate errors due to reagent and handling. In the present investigation, very clear solutions were obtained for all the samples and calibration standards. Solutions were analyzed by PerkinElmer® Model ELAN® DRC™ II ICP mass spectrometer (PerkinElmer, Inc., Shelton, CT, USA) at the CSIR-National Geophysical Research Institute (NGRI), Hyderabad, India. The sample introduction consisted of a standard Meinhard® nebulizer with a cyclonic spray chamber. All quantitative measurements were performed using the instrument software (ELAN v. 3.1). This software uses knowledge-driven routines in combination with numerical calculations (quantitative analysis) to perform an automated interpretation of the spectrum of interest. Several well-known isobaric interferences are programmed and the corrections are automatically applied [25]. ¹⁰³Rh was used as an internal standard and external drift was corrected by repeated analyses of a 1:5000 solution of JG-2, JG-3 and JB-2, which were also used as calibration standards accordingly. Instrument response was corroborated relative to two independent digestions of G-1 and G-2. Precision and accuracy are better than RSD 5% for the majority of trace elements.

4. Results

4.1. Field Descriptions

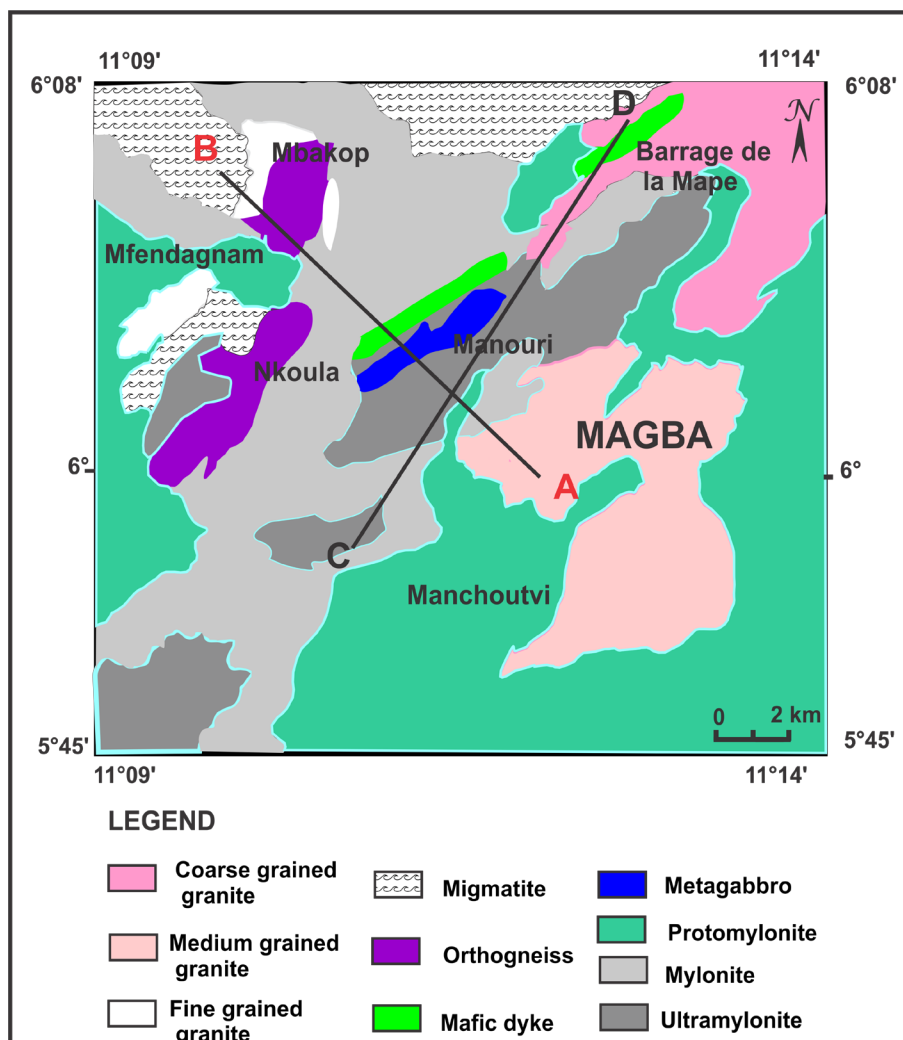
The distribution and disposition of the different litho units of the Magba area are shown in the geological map (Figures 3(a)-(c)). The description of major litho units, namely the Granites, orthogneisses, migmatites, meta-gabbro, mafic dykes and mylonites are documented here.

4.1.1. Granites

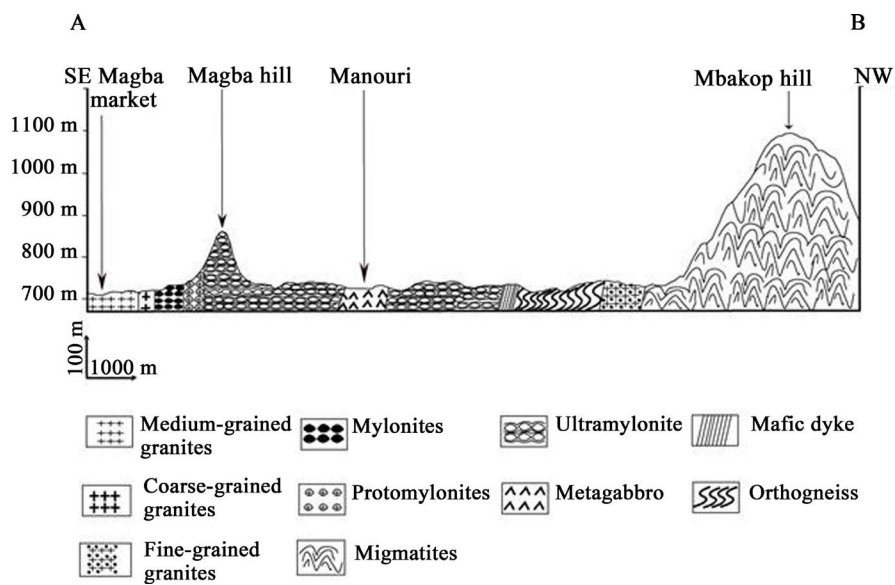
Depending on the grain size, granites are divided into coarse, medium and fine grained. Coarse grained granites outcrops are well exposed on the beds of Mape River and dam. They are massive and gray in color, made of feldspar phenocryst (4 cm × 2 cm) and quartz (1 cm × 0.5 cm) molded by biotite and amphibole flakes. Granites are intruded by mafic dyke oriented NE-SW (Figure 4(a)) of about ten meters long over fifteen centimeters wide. Thin secondary quartz and epidote veins (3 to 6 meters long and up to 3 cm wide) cross-cuts the outcrop, this could be a local deformation feature.

Medium-grained granites are located on the stream bed of Mape River at the Bridge level on Magba-Bankim road and the outcrops are exposed in the slab form (400 m long and 100 m wide). These rocks are massive, and at outcrop scale display pink color due to the abundance of potassium feldspar crystals. In Magba area, these rocks are gray in color, made of plagioclase phenocrysts, occur as relics in mylonitized host rocks.

Coarse-to-medium grained granites and protomylonites shows both magmatic stage pre-full crystallization fabric (pfc) and also solid-state deformation fabric. The magmatic stage fabric is defined either by the randomly



(a)



(b)

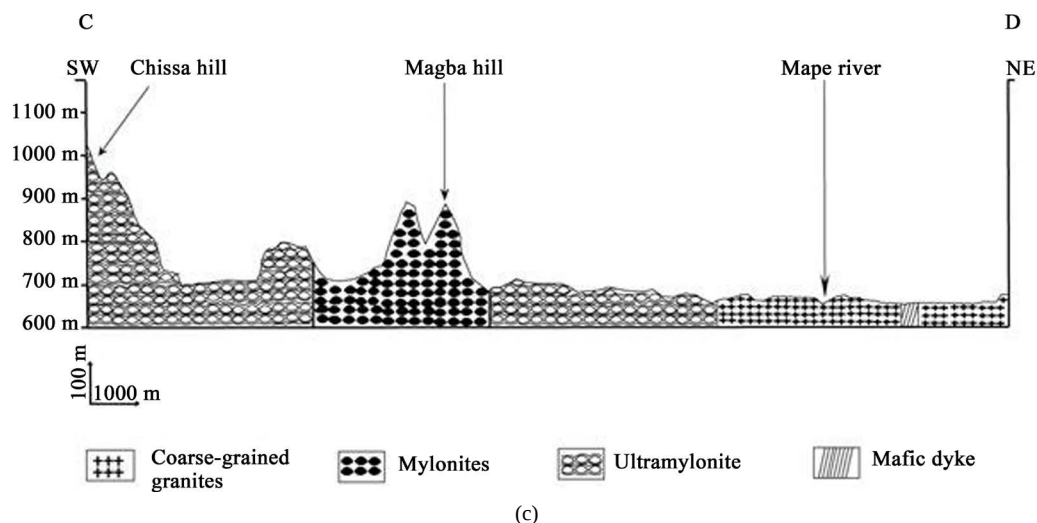


Figure 3. Rocks types of the study area. (a) Geological sketch map of the study area; (b) Cross-section from Magba Market to Mbakop hill; (c) Cross-section from chissa hill to Mape River.

oriented euhedral and subhedral feldspar phenocrysts or by an average sub-parallel alignment of the K-feldspar megacrysts in the less deformed granite. The mylonitic foliation (Sm), defined mainly by the preferential alignment of feldspar augen, ribbons of quartz, biotite and sericite streams, are subparallel to the magmatic stage deformation fabric.

Fine-grained granites occur as leucocratic at Mfendagnam and hololeucocratic at Mbakop (**Figure 4(b)**), often cross-cut by quartzofeldspathic veins. Essential minerals are millimetric sized quartz and feldspar. In Mfendagnam, the leucocratic fine grained granites occur in the dauphin back form (**Figure 4(c)**) and shark up to 1.5 m high, 8 m long and 2 m wide.

4.1.2. Orthogneiss

These rocks are exposed in the areas Mbakop, Nkoula, Mfendagnam and Mape dam. In Mbakop, orthogneisses are confined to the slopes of the MbaKop hill and occur in the form of ball and slab (6 m long and 4 m wide). Biotite flakes, feldspar and quartz crystals are found in the dark frame. Magmatic flow is evidenced by the alignment of feldspars and quartz crystals. In Nkoula and Mfendagnam areas, the foliation is defined by alternating dark mafic and clear quartzo-feldspathic bands. Feldspar and quartz minerals are millimetric size (2 mm × 1 mm) and well aligned in preferential direction.

“σ” porphyroblasts of feldspar are common in Mfendagnam migmatites. Amphibolite intrusions are seen in local scale in few outcrops (**Figure 4(d)**). In Mape dam area, the foliation is defined by alternating dark bands composed of ferromagnesian minerals and clear quartzo-feldspathic bands. The biotite lamellae (1 mm × 0.5 mm) are observed in the dark bands. At places, migmatization features are marked by the combination of granitic and gneissic components along with amphibolite intrusions.

4.1.3. Migmatites

Migmatitic outcrops are noticed in Mbakop, Mape dam and Chissa hill areas. In general, migmatites mark the passage of high-temperature metamorphic rocks to crustal igneous rocks. They result from the mineralogical reorganization by insitu partial melting of pre-existing rocks or granitic liquid injection in fractures.

In Mbakop area, these rocks are foliated, leucocratic and marked by a compositional banding characterized by alternating bands of gneisses and amphibolites. Later intrusions that are broadly parallel to the gneissic foliation are aplite and pegmatite veins and a metatextitic banding marked by vein injections. The migmatitic rock is also made of a light-colored mobilizate composing quartz and feldspar which could be the melt product, and of a restitic component constituting biotite, hornblende and pyroxene. The rock unit appears to be stretched and remobilised by quartzo-feldspathic components. These observations suggest that Mbakop migmatites are probable diatexites because of their heterogeneous appearance with the preponderant neosome (molten portion) in relation to paleosome (unmelted portion). The rock is also traversed by quartzo-feldspathic pegmatite vein probably

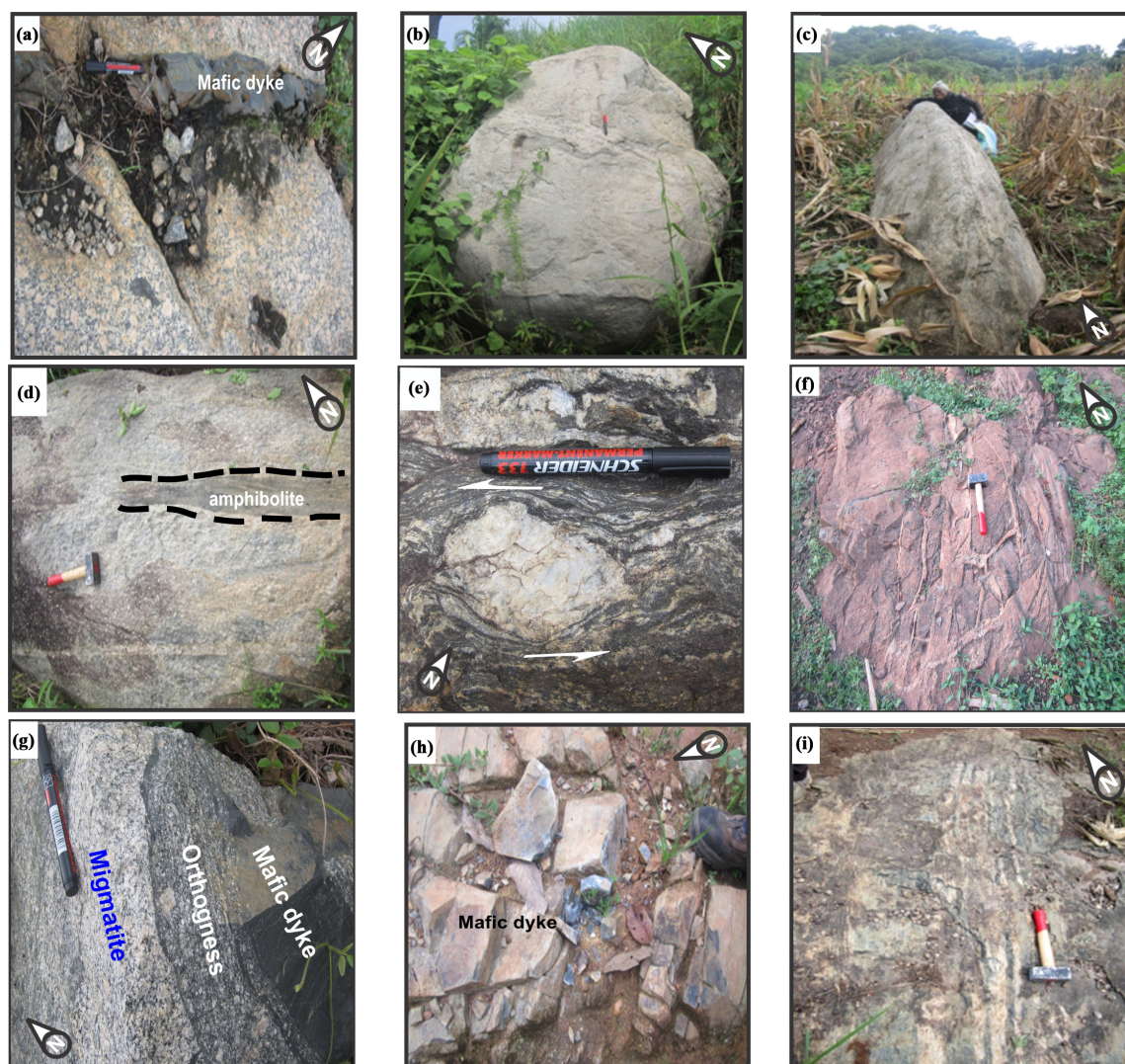


Figure 4. Field photographs of rock types in the study area. (a) Coarse grained granite outcrop with mafic vein in Mape dam. Note euhedral K-feldspar megacrysts in granite; (b) Hololeucocratic granitic outcrop in Mbakop; (c) Fine grained granite outcropping in the form of the back of dauphin in Mfedagnam; (d) Orthogneiss in Mfedgnam showing amphibolite intrusion and aligned k-feldspar porphyroblasts; (e) Migmatite with feldspar porphyroblast presenting recrystallization tail: note the sinistral sense of shear given by the porphyroblast; (f) Metagabbro outcrop presenting feldspar vein system in the form of a spiderweb; (g) Association of migmatite, orthogneiss and mafic dyke; (h) Mafic dyke outcrop in Mfembalou with NW-SE and NE-SW fracture directions; (i) Ultramylonite outcrop with alternated clair (quartzofeldspatic) and dark (mafic) band in Magba.

of granitic origin. Imbricated amphibolite boudins are also observed.

Mape dam, the migmatites are foliated, melanocratic, found in association with the orthogneisses, marked by the presence of large crystals of feldspar ($10\text{ cm} \times 6\text{ cm}$) injected into the gneissic unit during the partial melting of the parent amphibolite, then molded and guided by mafic minerals during deformation. Hence these feldspar crystals have a recrystallization tail and show the sinistral sense of shear (**Figure 4(e)**). Biotite occurs in the form of lamellae ($1\text{ cm} \times 0.5\text{ cm}$) and confined to the dark portion that constitutes restite. Quartz occurs as fine grains ($0.8\text{ cm} \times 0.6\text{ cm}$) within the melanocratic frame. All these features suggest that Mape migmatites are metatextitic. The migmatites of Chissa hill area are mainly dark, melanocratic and marked by intense folding of leucosomes.

4.1.4. Metagabbro

In Manouri area the metagabbro outcrops are noted in 100 m long over 30 m wide area. The rock is dark green-

ish in color and highly banded, having several fractures oriented in several directions and intersecting the sub vertical mylonitic foliation. The rock is traversed by quartzo-feldspathic veins of varying thickness (1 cm to 20 cm) parallel to the NE-SW banding direction. NE-SW trending prominent sub vertical stretching lineation defined by elongated feldspar grains on the foliation plane is recorded. Veins that host feldspar crystals are also molded by melted feldspar matrix. Joints (1 cm to 20 cm thickness) host molded feldspar porphyroblasts in the thin matrix of microcrystals of the same mineral. In places there is a feldspar vein system in the form of a spider web around the centimetric to decimetric block of gabbro (**Figure 4(f)**). Outcrops exhibit dome and basin structures which demonstrate lateral constraints.

4.1.5. Mafic Dykes

The mafic dykes are exposed in Mape dam and Mfembalouh area on Magba-Mbakop road. In Mape dam area, they occur as NE-SW intrusions of 10m long and 15cm width and are associated to migmatite and orthogneiss (**Figure 4(g)**). The rock is massive with aphyric texture and intrudes the granite outcrop. In Mfembalouh, these rocks are massive, oriented in NE-SW direction, occur in relatively wider extent (30 m long and 10 m wide) and is highly fractured, mainly in the NW-SE and NE-SW directions, forming a kind of grid system (**Figure 4(h)**).

4.1.6. Mylonites

Mylonites are well distributed in the study area, along the NE and SE of Magba hill, in Manouri, Nkoulou areas and Chissa hill. Depending on the extent of deformation, and subsequent retention of the parent rock (granite), the mylonites are divided into three groups: protomylonites (initial rock proportion $\geq 50\%$), mylonites ($10\% \leq$ initial rock proportion $\leq 50\%$), and ultramylonites (initial rock proportion $\leq 10\%$). Protomylonites and mylonites are noticed in Magba hill, Chissa hill, Mfendagnam, and Mbakop areas while the ultramylonites are noticed in Magba and Chissa hill areas.

In Magba area, the protomylonites occur as massive slabs, with feldspars and quartz as major minerals that constitute the rock. Thin secondary veins filled with epidote and/or chlorites are noticed traversing in all directions, while at some places the quartzo-feldspathic veins are observed intersecting the mylonitic foliation. Few mafic material injections (amphibolite) of varying thickness (3 - 10 cm) are traversed parallel to the foliation. Depending on cross-cutting chronology, mafic injections could be older than quartzo-feldspathic veins. In NE of Magba hill area, the mylonites have similar behavior as the earlier outcrops described, except that at local scale, magmatic quartzo-feldspathic ingestions (~0.5 m thick) are noticed containing large feldspar porphyroclasts oriented perpendicular to the mylonitic foliation. At Mfendagnam area, the rock still retains few probable protholitic structures such as aligned feldspar and quartz porphyroclasts reoriented along the mylonitic foliation. The clasts exhibit recrystallization tails of “ σ ” shape symptomatic of a sinistral shearing movement. The outcrop is traversed by quartz veins subparallel to the low amplitude mylonitic foliation. At Chissa hill area, the mylonites are locally traversed by quartzo-feldspathic veins those are variably folded.

Ultramylonites are well exposed at the NE and SE of Magba hill, Nkoup river bed and Chissa hill, and are distinct from other rock types of the study area due to the pronounced enrichment of chlorite. Feldspar porphyroclasts are fewer and have rounded to elliptical shape, sparsely occur in a very fine groundmass composed of quartz, feldspar and micas. Intense mylonitic foliation (S_m), defined by subparallel alignment of biotite and quartz ribbons in the matrix, give rise to subparallel dark and clear bands enriched and devoid of biotite respectively (**Figure 4(i)**). Stair stepping of the feldspar porphyroclasts with their long axis at an acute angle with the mylonitic foliation, together with strike-slip sheared quartzo-feldspathic veins indicates a sinistral sense of shear movement of the rock. Ultramylonite zones display extreme grain size reduction and near absence of visible feldspar porphyroclasts and neocrystallisation of chlorite and sericite transformed the rock into foliated quartz-chlorite rock or phyllonite. The different subzones comprising protomylonite, mylonite and ultramylonite within the sheared granite corresponds to the progressive increase in strain, as evident from grain size reduction, progressive disappearance of feldspar porphyroclasts and generation of sericite mica and chlorite, decrease in angle between the S- and C-planes and increasing aspect ratios of the quartz ribbons. Heterogeneous deformation greatly modified the grain size and texture of the rock within Magba shear zone.

4.2. Petrography

Five major petrographic units have been recorded on the study area. They are granite, orthogneiss, migmatites, metagabbro, mafic dykes and mylonites. Petrography and structural features of these rocks are documented on

Table 1.**4.2.1. Granites**

The granites are coarse to fine-grained and predominantly porphyritic in nature (**Figure 5(a)** and **Figure 5(b)**). They are composed of quartz (28%), orthoclase (15%), plagioclase (10%), pyroxene (8%), biotite (7%), amphibole (5%), microcline (5%) and muscovite (3%) as principal minerals, while allanite (4%), sphene (2%), apatite (2%), epidote (2%) and opaques (1%) are the accessory minerals. Secondary minerals are represented by myrmekite (2%), chlorite (1%), sericite (3%) and perthite (2%). Quartz is in the form of polycrystalline ribbons of varying size having gears and grain boundary migration (**Figure 5(b)**). Quartz grains occasionally react with plagioclase to form myrmekites at the grain boundaries (**Figure 5(c)**).

Plagioclase crystals are sub-euhedral and exhibit albite twins. Some crystals underwent sericitization while orthoclase crystals underwent perthitization reactions (**Figure 5(d)**). Pyroxene is in the form of sub-euhedral, moderately elongated phenocrysts. Amphibole is represented by the green hornblende, occur in the sheet form similar to the amphibole fish. It contains sphene inclusions and associated with biotites and pyroxenes. Biotites occur as elongated fine fibres, mostly transformed into chlorite. Some biotite fibres contain opaque inclusions while others are resorbed by quartz. Sphene is in the form of columnar rod or sub-rounded form with their characteristic twins.

4.2.2. Orthogneiss

Textures that characterize orthogneisses include porphyroblastic, granoblastic (**Figure 5(e)**) and lepidoblastic. The major minerals are quartz (30%), plagioclase (20%), orthoclase (15%), pyroxene (12%), and amphibole (12%). Chlorite (8%) is secondary mineral while sphene (2%) and epidote (1%) are accessory minerals. Quartz is more abundant in the rock and is in the form of polycrystalline ribbons composed of both porphyroblasts and microblasts. Elongated ribbons of quartz show the evidence for dynamic recrystallisation in the form of development of sub grains, their rotation and recrystallization (**Figure 5(f)**).

Quartz porphyroblasts are abundant in Mape dam orthogneiss while quartz microblasts filling the mineral interstices and cracks are observed in the orthogneisses of Mbakop area. Quartz is also present in the form of elongated fibers forming the pressure fringe around the pyrite sub rounded mineral. Plagioclase is in the form of sub-euhedral crystals generally molded by biotite and chlorite. In places plagioclase crystals present displaced grain fragment or micro fault and curved shapes while others display zoning, typical for magmatic crystallization. Biotite is in the form of flake and fibers with more or less frayed edge. Locally biotite is transformed into

Table 1. Petrography and structural features of Magba rocks.

Suite	Major and minor minerals	Accessory minerals	Texture and mineral reactions	Deformation
<i>Coarse to fine-grained granites</i>	Qtz + Or + Pl + Py + Bt + Amp + Mi + Mus	Sph + Aln + Ap + Op + Ep	Porphyritic texture, myrmekitisation chloritisation perthitisation and sericitisation	Undeformed to Mildly deformed (fracture and kink deformation, pressure shadow)
<i>Orthogneiss</i>	Qtz + Or + Pl + Py + Amp	Sph + Ep	Porphyroblastic, granoblastic and lepidoblastic textures chloritisation	Slightly deformed (breaking and curved shape, amphibole fish, cracks)
<i>Migmatites</i>	Qtz + Bt + Pl	Ap + Op	Grano-Porphyroblastic texture, chloritisation and myrmekitisation	Slightly deformed (curved Bt flake, pressure shadow, kink deformation)
<i>Metagabbro</i>	Or + Pl + Py + Bt + Amp + Mi	Op	Porphyroblastic texture, sericitization	Mildly Deformed (cracks on Pl)
<i>Mafic dykes</i>	Amp + Px + Or	Ep + Op + Zrn	Cataclastic texture, chloritisation	Highly Deformed (curved branching amphibole, veins fractures and fault)
<i>Mylonites</i>	Qtz + Or + Pl + Py + Bt + Amp + Mi	Zrn + Sph + Op + Ep + Tr + Ap + Leu	Ocellar, Mylonitic and cataclastic texture, banding and foliation present, chloritisation and myrmekitisation	Slightly to highly deformed (cracks and kink deformation, pressure shadow, σ and δ porphyroblast, fractures, fold, faults, Joints,

Qtz = quartz, Pl = plagioclase, Bt = biotite, Or = orthoclase, Mi = microcline, Mus = muscovite, Sph = sphene, Px = pyroxene, Op = opaques, Zrn = zircon, Ap = apatite, Ep = epidote, Aln = allanite, Tr = tourmaline, Amp = amphibole, Leu = leucosene

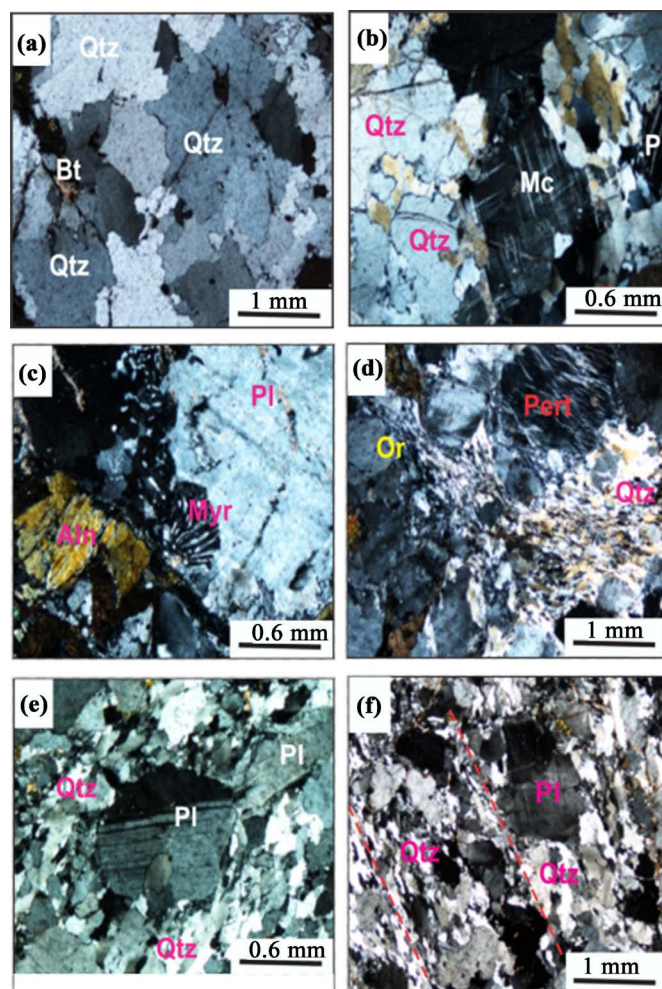


Figure 5. Photomicrographs of rock textures and mineral reactions (Cross Polarized Light). (a) Coarse grained texture in granite presenting tiled and imbricated quartz phenocrysts; (b) Quartz presenting gears and grain boundary migration. These are evidence for dynamic recrystallization by grain boundary migration; (c) Myrmekitic texture marked by intergrowth of quartz crystal on plagioclase in dilational sites (“pressure shadows”) around K-feldspar phenocrysts; (d) Perthitization of K-Feldspar. Note also recrystallized stream quartz molding feldspar crystals; (e) Grano-lepidoblastic texture in orthogneiss. Note rotated plagioclase surrounded by recrystallized quartz subgrains. This rock is part of a suite that is syntectonic with a major deformation event. The shape fabric and the intracrystalline deformation features can therefore be interpreted as sub-magmatic; (f) Typical fabric of dynamically recrystallized quartz formed by sub grain rotation (SGR) recrystallization. Note also the alignment of recrystallized quartz and feldspar.

chlorite. Amphibole (green hornblende) is anhedral or sub-euhedral, flaky sometimes occurs in the form of “amphibole fish”. Orthoclase is less abundant in the rock and occurs as large sub-euhedral and anhedral crystals with carlsbad twins, often display cracks filled with biotite. Pyroxenes occur in clusters in Mape dam orthogneisses, are diamond-shaped while in Mbakop orthogneisses, they occur as twinned or zoned slats (**Figure 6(a)**). Spinel is very rare in Mape dam orthogneiss, but commonly seen in those of Mbakop, while acicular epidote is noticed in plagioclase porphyroblasts.

4.2.3. Migmatites

Migmatites exhibit grano-porphyroblastic texture. The mineralogy is quartz (40%), biotite (15%), myrmekite (2%), chlorite (8%), plagioclase (25%), apatite (4%) microcline (5%) and opaque (1%). In Mape dam, there are two generations of quartz, the first generation being exhibited as monocrystalline ribbons having gears with undulatory extinction while the second-generation quartz is the product of recrystallization and filled along the interstices between the primary minerals resulting in migmatitic foliation to the rock. Plagioclase occurs as sub-

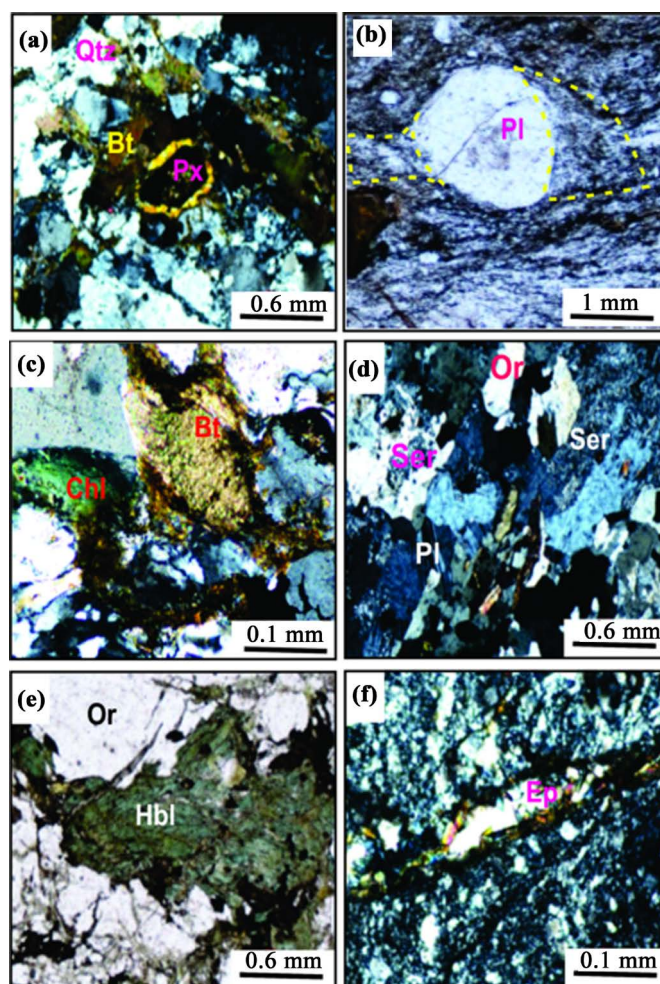


Figure 6. Photomicrographs showing rock textures and mineral reactions. (a, c, d, e = Cross Polarized Light; b and f = Plane Polarized Light). (a) Corona texture on altered pyroxene (Px); (b) Plagioclase (Pl) porphyroclasts presenting pressure shadow filled by quartz (Qtz) and biotite (Bt); (c) Chloritization of biotite (Bt); (d) Porphyroblastic texture in metagabbro. Note the sericitization of plagioclase (Pl); (e) Curved branching amphibole (Hbl) on Mape dam mafic dyke. This shape is exclusively found in mafic dykes; (f) Antiaxial epidote (Ep) vein in mafic dykes. Epidote minerals are parallel or perpendicular to the walls of the vein, leaving gap in the center.

euohedral crystals with sub-rounded contours molded by recrystallized quartz crystals and biotite lamellae. Some crystals have fractures bands and kink structures due to tectonic stresses. Most of the crystals are deformed and contain pressure shadows or recrystallization tails filled by biotite or quartz (**Figure 6(b)**). Biotite molds feldspar and quartz porphyroblasts giving the appearance of spider network. Some flakes are transformed into chlorite (**Figure 6(c)**). Microcline is anhedral and presents slightly curved polysynthetic twins of albite and pericline forming a shimmering fine grid with low to very low relief.

4.2.4. Metagabbros

Metagabbros of Magba region exhibit porphyroblastic textures (**Figure 6(d)**) and made of plagioclase (40%), microcline (15%), orthoclase (8%), pyroxene (5%), amphibole (4%) and biotite (2%) as primary minerals while only sericite (25%) is the secondary mineral and opaque (1%) accessory mineral. Plagioclase crystals are more abundant, are sub-euhedral and exhibit polysynthetic twinning. Though very limited, also occur as inclusions in orthoclase. Sericite occur in the form of pasty bands, developed due to sericitization of plagioclase (**Figure 6(d)**). Microcline crystals sometimes contain amphibole inclusions. Orthoclase crystals are less abundant in the rock while pyroxene is in the form of elongated strips with rectangular sections. Amphiboles are very rare in the rock and occur as thin flakes. Opaque minerals are euhedral sometime with hexagonal form and disseminated in the

rock.

4.2.5. Mafic Dykes

These rocks exhibit cataclastic textures marked by alternating layers of dark and light colored minerals. Crushed minerals are indistinguishable microscopically. Some phenocrysts that resisted crushing are visible such as amphibole (30%), orthoclase (25%), chlorite (20%), pyroxene (15%), epidote (6%), zircon (5%) and oxides (4%). Amphibole is represented by the green hornblende and occurs as clusters of curved branching flakes that are a characteristic of Magba dykes (**Figure 6(e)**). Sometimes the amphiboles occur as sub-rounded to sub-euhedral crystals, as well as like “amphibole fish” shape suggesting their growth during deformation. Chlorites are the alteration products of amphiboles and they fill the interstices left by previously crystallized minerals. Pyroxenes occur as phenocrysts of uneven square or diamond-shaped. Orthoclase occurs as largely fractured anhedral phenocrysts of variable sizes, includes almond-shaped and “ σ ” type porphyroclasts, indicating the sinistral shear sense these rocks had undergone. Few orthoclase crystals also bear amphibole and opaque inclusions. Epidotes occur as euhedral to sub-euhedral crystals. In the matrix they are anhedral while in the veins they are particularly in euhedral form, oriented perpendicular to the walls of the vein leaving gap in the center (**Figure 6(f)**). Opaques are less abundant, euhedral to sub-euhedral and are found in fractures and mineral interstices. Zircon is the least visible mineral in the rock. It is euhedral with high relief and presents sometimes a corona due to its radioactivity.

4.2.6. Mylonite

Strain heterogeneity within the Magba Shear Zone is evident from the development of proto- to ultramylonite zones, with granoclastic (**Figure 7(a)**), ocellar mylonitic texture (**Figure 7(b)**), and cataclastic textures (**Figure 7(c)**) respectively for protomylonite, mylonite and ultramylonites. Primary minerals are quartz (20 %), orthoclase (15%), plagioclase (10%), biotite (8%), amphibole (6%), microcline (5%); secondary minerals are sericite (8%), myrmekite (2%) and chlorite (10%) while zircon (2%), sphene (2%), tourmaline (1%), epidote (1%), apatite (1%), leucoxene (5%) and opaques (4%) are accessory minerals. Pyroxenes are confined to mylonites while amphiboles and microclines are observed in mylonites and ultramylonites. Protomylonites are characterized by weakly developed fabric, defined by the elongated quartz and feldspar grains. Quartz and orthoclase porphyroclasts yield to brittle failure producing fragmented grains and also to crystal plastic deformation resulting in deformation lamellae and grain refinement through recrystallization (**Figure 7(d)**).

Quartz phenocrysts exhibit globular and granular shapes with undulatory extinction and are scattered in the crushed recrystallized matrix while microcrysts form bands parallel to biotite (“biotite fish”) layers giving the rock a curved mylonitic foliation (**Figure 7(e)**). At Mbakop, some biotite flakes are folded and present curved pressure shadow (**Figure 7(f)**). Some quartzofeldspathic layers are folded under S type shape indicating the sinistral sense of shear the rock had undergone (**Figure 8(a)**).

Most of plagioclase and orthoclase porphyroclasts exhibit “ σ ” or “ δ ” (**Figure 8(b)**), recrystallization tails and other rolling structures giving the sinistral shear sense to the rock. Highly fractured plagioclases are also present (**Figure 8(c)**). Sericitization is noted only in protomylonites while myrmekitization is observed in protomylonites and mylonites. Perthitic texture marked by plagioclase band containing albite islets is also noted. Feldspar phenocrysts exhibit simple and staircase type displacements (**Figure 8(d)**) and “chevron”/“kink” type deformation (**Figure 8(e)**).

Amphiboles are represented by green hornblende and glaucophane. Green hornblende is sub-euhedral and occur as curved tracks associated with biotite, and also as “amphibole fish” (**Figure 8(f)**), indicating their emplacement during deformation. Retrograde metamorphism marked by amphibole converting to chlorite is observed at few places. Opaques and zircon inclusions are observed in the margins of biotites, and such inclusions are identified in orthoclase also. Most biotite flakes underwent early chloritization. Leucoxene and tourmaline are euhedral and only found in ultramylonite while apatites are found in protomylonites and mylonites.

4.3. Geochemistry

4.3.1. Major Element

Major and trace element compositions of the analyzed samples are given in **Table 2**. The rocks exhibit important variations in concentrations of major elements. They are basic to acid with low to high SiO₂ concentrations with

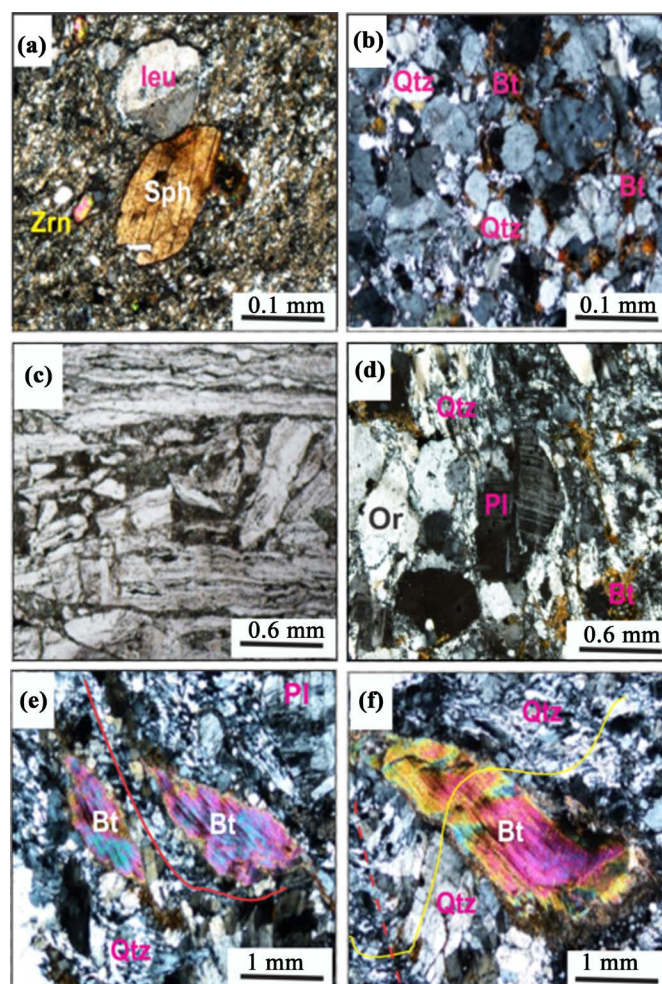


Figure 7. Photomicrographs presenting microstructures and rock textures. (a, b, d, e = Cross Polarized Light; c and f = Plane Polarized Light). (a) Granoclastic texture in mylonites. Note totally converted sphene (Sph) into Leucoxene (Leu); (b) Ocellar mylonitic texture in protomylonite; (c) Cataclastic texture in ultramylonite; (d) Deformation lamellae and grain refinement through recrystallization; (e) “Mica fish” and quartz (Qtz) mineral alignment describing curved foliation defined by biotite and quartz lying at angle of about 45° to the upper edge of the plate. It curves smoothly to give the sinistral sense of shear to the rock; (f) Biotite flake with curved pressure shadow; also notice fold highlighted by the curved (crenulated) foliation defined by rotated aligned quartz.

lowest (48.61wt.%) value in metagabbro and the highest (73.40 wt.%) in mylonite. They plot in the gabbro, monzodiorite, monzonite syenite, quartz monzonite, granodiorite and diorite field in the diagram of [26] (**Figure 9**). In the A/CNK and A/NK diagram after [27] all the samples are metaluminous with A/CNK and NK/A ratios ranging from 0.38 to 0.87, and 0.40 to 1.23 respectively and Al_2O_3 values ranging from 11.54 to 16.06 wt.% (**Figure 10**). The Al_2O_3 (10.68 - 16.06) and Fe_2O_3 contents (0.53 - 10.55 wt.%) are high while MgO (0.23 - 9.12 wt.%) and MnO (0.01 - 0.17 wt.%) contents are low. CaO (0.34 - 11.4 wt.%), Na_2O (2.38 - 5.22 wt.%), K_2O (1.31 - 9.85 wt.%), TiO_2 (0.01 - 2 wt.%) and P_2O_5 (0.04 - 0.84 wt.%) contents are low to high with highest value in metagabbro (TiO_2 = 2 wt.%, and P_2O_5 = 0.84 wt.%). TiO_2 bearing mineral phases are abundant in mylonite and mafic dykes and rare in metagabbro. The loss on ignition (L.O.I = 0.20 - 1.76 wt.%) values are low, attesting to the freshness of the rocks or the low proportion of fluid in the magma. This content is justified by the rarity of secondary minerals in the rock. All the sample have $\text{Na}_2\text{O}/\text{K}_2\text{O}$ ratios ranging from 0.27 to 2.18 and $\text{K}_2\text{O}/\text{Na}_2\text{O}$ from 0.46 to 3.59, showing the sodic character of rocks and plot in high-k calc-alkaline and shoshonitic field of the diagram after [28] (**Figure 11**).

Bivariate plots of MgO with SiO_2 , CaO and Ni show a distinct linear regression (either positive or negative slope) for the mafic rocks of Magba. On the Harker diagrams (**Figure 12**), the abundances of TiO_2 , Al_2O_3 , MnO,

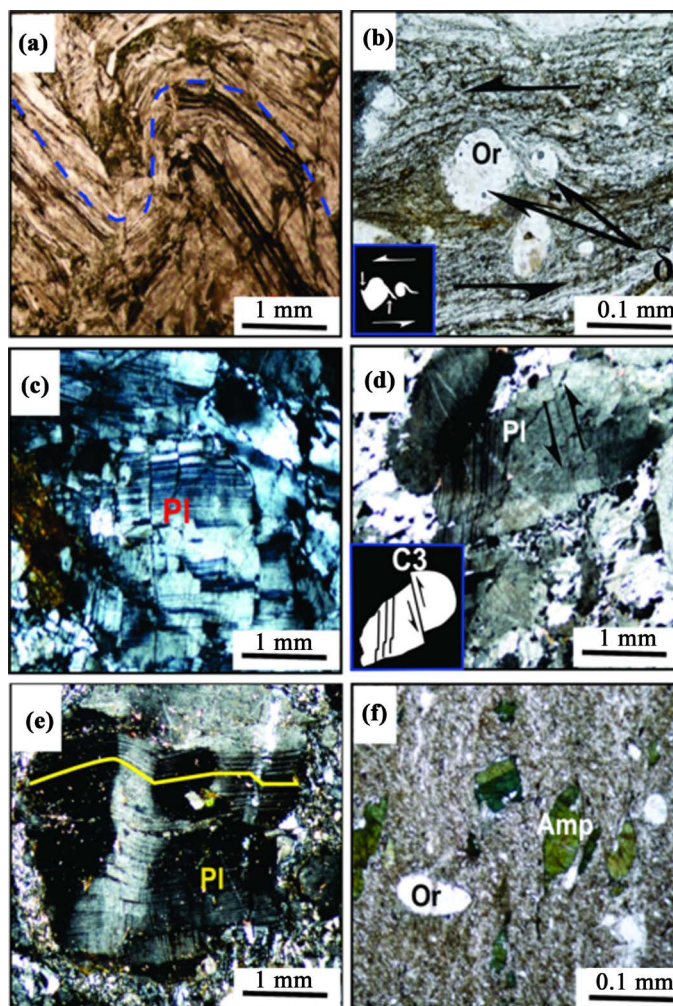


Figure 8. Photomicrographs showing microstructures and kinematic indicators (c, d, e = Cross Polarized Light; a, b, f = Plane Polarized Light). (a) “S” type microfold in mylonite presenting the sinistral sense of shear; (b) “ δ ” and “ σ ” feldspar porphyroclast on ultramylonite. The deflection of the tails around the porphyroclasts shows clearly the sinistral sense of shear; (c) Highly fractured plagioclase porphyroclast in mylonite; (d) Sinistral strike slip shears (C3) on plagioclase porphyroclast in Magba protomylonite. Also note the curved twins and displaced grain fragments; (e) Kink deformation on plagioclase phenocryst; (f) “Amphibole fish” on ultramylonite.

MgO, CaO, Na₂O, Fe₂O₃ total, and P₂O₅ decrease with increasing SiO₂. However, K₂O correlates positively with SiO₂, which may imply that alkali feldspar persisted in the melt phase until the later stages of magmatic evolution.

4.3.2. Trace Elements

Within the minor and trace element suites, Cr (08.81 - 451.52 ppm), Vanadium (3.25 - 747.53 ppm), Cu^{per} (0.14 - 144.83) and Zn (5.54 - 121.72 ppm), are dominant. Co (0.82 - 59.31 ppm), Sc (0.50 - 33.89 ppm) and Ni (0.73 - 144.83 ppm), contents are low to moderate. Barium (60.63 to 2662.86 ppm) content in orthogneiss is higher than in other rocks (**Table 2**). The lowest contents in Hf, Zr, and Pb are also obtained in mylonite (**Table 2**).

Samples are characterized by low to high Sr (36.40 - 1361.21 ppm) and Y (1.29 - 89.19 ppm) but low Yb (0.05 - 6.95 ppm) concentrations (**Table 2**). They are enriched in LREE but depleted in HREE, with (La/Yb)_N = 1.11 - 197.67 (chondrite normalized value are after [29]). They present a flat HREE pattern and weakly negative to positive Eu anomalies (dEu = 0.14 - 1.44; dEu = Eu_N/SQRT (Sm_N - Gd_N)) in chondrite normalized REE diagram and variable fractionation (**Table 2**). Therefore, two distinct types of REE patterns, viz., with and

without Eu negative anomaly (Figure 13) was observed with light rare earth elements (LREE) enrichment depicting the evolution of Magba rocks probably through fractional crystallization.

Patterns show also enrichment in Ba, K, Pb, Nd, Sm and depletion in Nb, U, La, Ce, Pr, Yb and Ti in the primitive mantle normalized spidergram (Figure 14; primitive mantle values were taken after [30]. The chondrite-normalized [29] patterns present also the parallel spectra for gabbro and mafic dykes samples, negative Ce

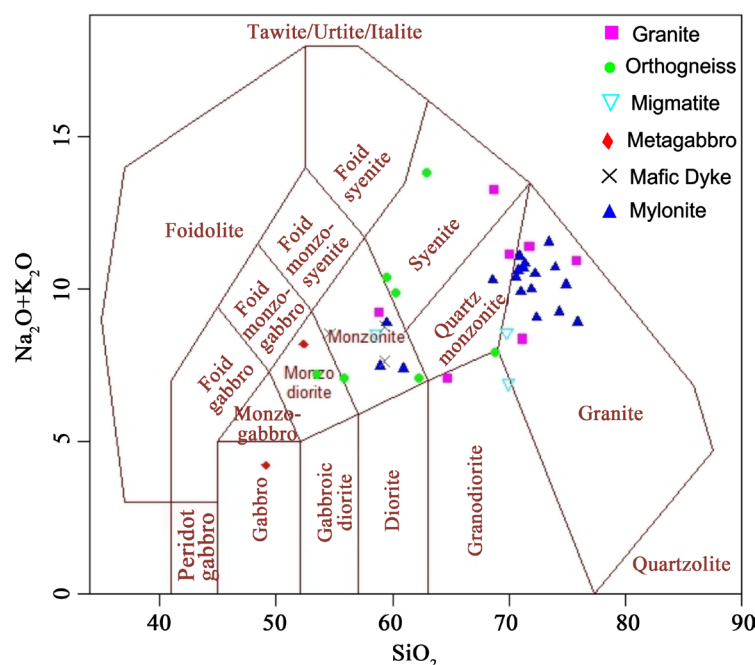


Figure 9. Classification diagram of Magba rocks after [26].

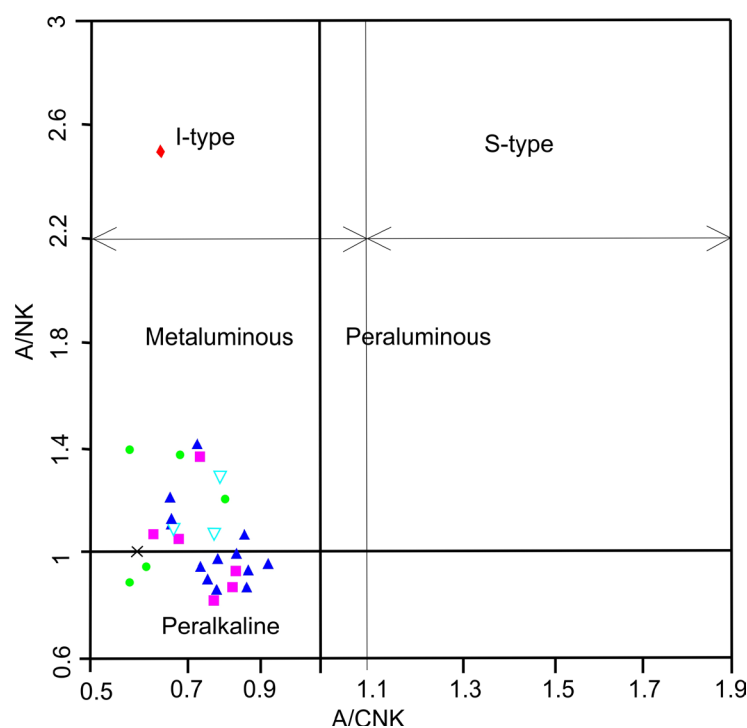


Figure 10. A/NK versus A/CNK diagram showing metaluminous character of the Magba rocks. Symbols are the same as in Figure 9.

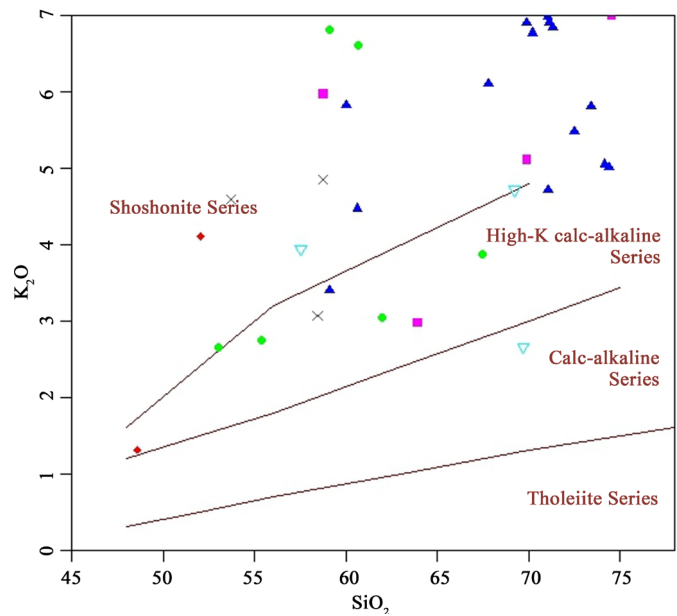


Figure 11. K_2O versus SiO_2 diagram after [28] Symbols are the same as in Figure 9.

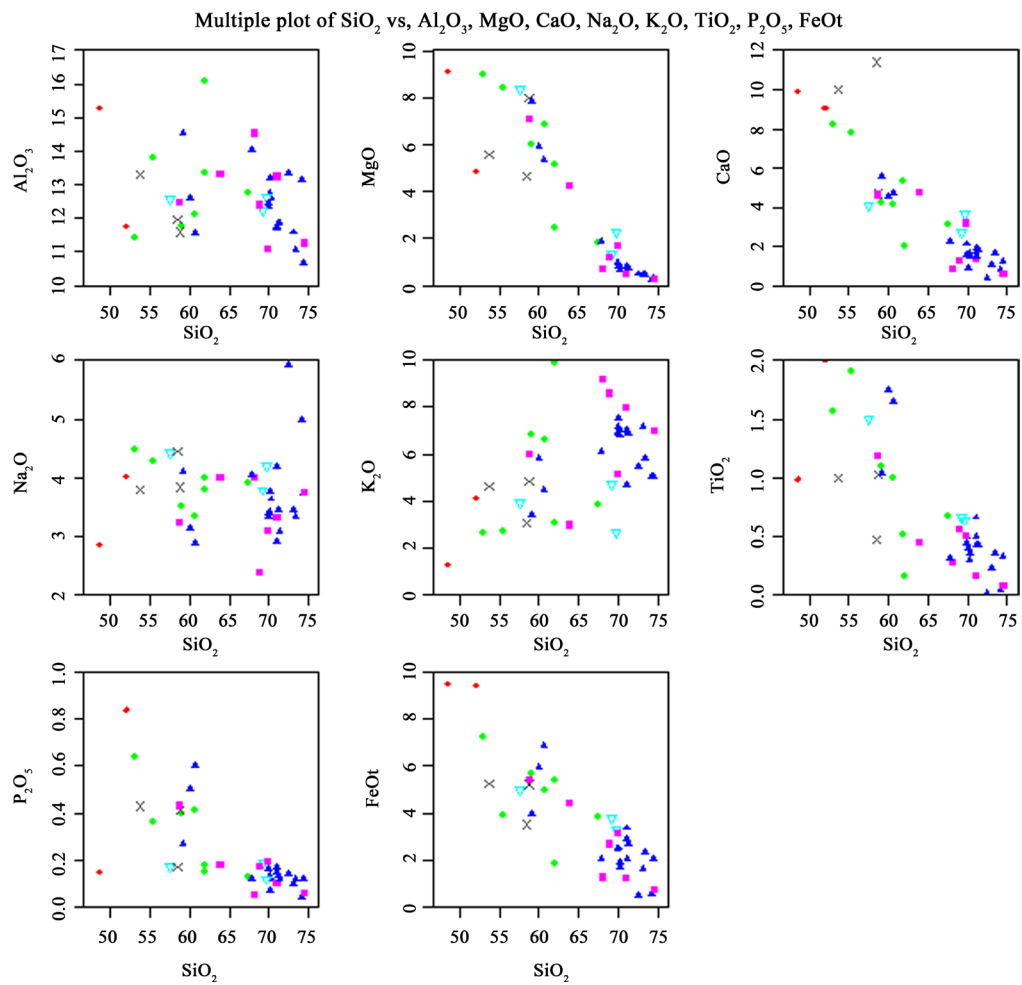


Figure 12. Harker diagrams for Magba rocks. Symbols are the same as in Figure 9.

Table 2. Whole rock majors (wt. %) and traces element (ppm) data including rare earth element from Magba rocks.

Seq.	1	2	3	4	5	6	7	8	9	10
Sample	NTB3(G)	NTB4(G)	NTB5(G)	NTB1A(G)	NTMP1(G)	MAPE(G)	NT8(G L)	NT1(Ort)	NT16(Ort)	NT2(Ort)
SiO ₂	58.8	63.9	69.0	69.9	74.6	68.2	71.1	55.4	59.1	62.0
TiO ₂	1.2	0.5	0.6	0.5	0.1	0.3	0.2	1.9	1.1	0.2
Al ₂ O ₃	12.5	13.3	12.4	11.1	11.3	14.5	13.2	13.8	11.8	16.1
Fe ₂ O ₃	6.0	4.9	3.0	3.5	0.8	1.4	1.4	4.3	6.3	2.0
MnO	0.1	0.1	0.0	0.1	0.0	0.0	0.0	0.2	0.1	0.0
MgO	7.1	4.2	1.2	1.7	0.3	0.7	0.5	8.4	6.0	2.5
CaO	4.6	4.8	1.2	3.2	0.6	0.9	1.3	7.8	4.2	2.0
K ₂ O	6.0	3.0	8.6	5.1	7.0	9.1	8.0	2.7	6.8	9.9
Na ₂ O	3.2	4.0	2.4	3.1	3.8	4.0	3.3	4.3	3.5	3.8
P ₂ O ₅	0.4	0.2	0.2	0.2	0.1	0.1	0.1	0.4	0.4	0.2
LOI	0.8	0.2	0.2	1.8	0.3	0.5	0.2	0.4	2.4	0.3
Total	100.6	98.9	98.6	100.0	98.7	99.6	99.3	99.5	101.7	98.9
Sc	9.1	6.3	5.4	9.7	0.9	2.3	0.5	19.0	12.5	2.6
V	28.5	16.8	7.5	24.9	3.7	6.8	6.3	211.1	30.0	17.2
Cr	11.9	11.6	12.9	10.8	13.7	12.0	8.8	82.4	10.3	15.8
Co	10.0	9.0	4.7	8.6	2.3	2.3	1.4	18.8	13.8	4.8
Ni	2.3	1.8	1.5	1.6	2.0	2.2	1.0	2.0	2.6	2.0
Cu	0.2	0.5	0.1	0.2	0.2	0.2	0.2	0.7	0.5	0.4
Zn	25.3	19.1	8.8	11.8	9.6	23.8	13.0	39.3	31.0	18.0
Ga	26.5	17.6	31.2	26.0	12.7	24.1	8.6	28.9	33.3	26.1
Rb	226.8	70.4	249.9	146.4	163.4	361.9	76.0	120.1	265.2	198.1
Sr	997.4	689.2	250.0	792.1	118.1	170.6	200.4	393.6	668.7	633.7
Y	31.9	9.7	12.6	29.9	6.1	61.7	11.3	89.2	50.4	6.3
Zr	436.5	38.8	435.0	346.1	90.7	290.8	69.8	312.4	426.0	93.8
Nb	18.4	4.3	15.2	19.2	4.7	29.4	4.6	47.5	51.2	6.1
Cs	8.3	1.2	2.0	1.7	1.3	3.5	0.9	8.1	6.2	3.7
Ba	1693.2	1167.2	1664.6	1822.5	559.4	443.8	756.6	251.7	2125.4	2662.9
Hf	13.6	1.4	13.4	9.6	3.4	9.3	2.6	11.3	13.2	3.1
Ta	0.8	0.2	0.3	1.3	0.6	2.9	0.2	4.1	1.8	0.1
Pb	26.1	19.8	40.4	20.4	22.8	35.8	20.6	77.5	45.2	68.1
Th	16.0	2.5	93.9	15.9	39.6	17.1	6.0	18.0	32.6	7.2
U	4.5	0.5	3.0	4.4	1.3	11.7	1.7	11.4	6.1	1.2
La	99.0	15.2	193.5	100.5	22.1	88.8	27.6	73.3	143.0	50.3
Ce	207.4	32.2	410.9	202.7	40.4	164.4	46.4	189.9	280.0	91.5
Pr	22.5	3.8	43.6	21.9	3.9	18.1	5.3	25.2	28.5	9.5
Nd	87.7	15.8	156.3	85.1	12.7	66.4	19.0	108.5	104.1	34.7
Sm	14.0	2.8	19.6	13.5	1.6	10.9	2.8	20.5	15.6	5.0
Eu	2.5	0.8	1.1	2.2	0.4	1.2	0.5	4.1	2.9	1.3
Gd	7.6	1.7	7.9	7.4	0.9	7.1	1.8	13.5	9.1	2.6
Tb	1.0	0.2	0.8	1.0	0.1	1.2	0.2	2.1	1.3	0.3
Dy	5.6	1.6	3.1	5.5	0.8	8.2	1.5	14.0	7.7	1.2
Ho	1.0	0.3	0.4	1.0	0.2	1.8	0.3	2.8	1.5	0.2

Continued

Er	2.5	0.8	1.0	2.5	0.4	4.8	0.7	7.2	3.9	0.4
Tm	0.3	0.1	0.1	0.4	0.1	0.7	0.1	1.0	0.5	0.1
Yb	2.1	0.7	0.7	2.3	0.4	4.9	0.7	6.8	3.8	0.3
Lu	0.3	0.1	0.1	0.3	0.1	0.7	0.1	1.0	0.5	0.0
(La/Yb)N	32.2	14.6	197.7	30.9	35.4	12.5	28.2	7.5	26.4	114.7
En/Eu*	0.7	1.0	0.3	0.7	1.0	0.4	0.6	0.8	0.7	1.1
Sr/Y	31.3	71.4	19.9	26.5	19.4	2.8	17.7	4.4	13.3	101.2
Al ₂ O ₃ /TiO ₂	10.6	29.5	22.1	22.2	140.6	51.9	82.7	7.2	10.7	100.4
Na ₂ O/K ₂ O	0.5	1.3	0.3	0.6	0.5	0.4	0.4	1.6	0.5	0.4
K ₂ O/Na ₂ O	1.8	0.7	3.6	1.7	1.9	2.3	2.4	0.6	1.9	2.6
Al ₂ O ₃ /Na ₂ O	3.9	3.3	5.2	3.6	3.0	3.6	4.0	3.2	3.3	4.2
A/CNK	0.6	0.7	0.8	0.7	0.8	0.8	0.8	0.6	0.6	0.8
A/NK	1.1	1.4	0.9	1.0	0.8	0.9	0.9	1.4	0.9	0.9
NK/A	0.9	0.7	1.1	1.0	1.2	1.1	1.1	0.7	1.1	1.1
Seq.	11	12	13	14	15	16	17	18	19	20
Sample	NTB1B (Ort)	NT4(Ort)	NT9(Ort)	NTB6(Ort)	NT5(Mig)	NT6A(Mig)	NT3(Mig)	NT12(Gb)	NT12A(Gb)	NTB1(D)
SiO ₂	60.67	67.47	53.03	61.96	57.52	69.21	69.72	52.07	48.61	58.74
TiO ₂	1.00	0.67	1.56	0.51	1.50	0.66	0.64	2.00	0.99	1.03
Al ₂ O ₃	12.10	12.74	11.42	13.36	12.57	12.24	12.64	11.76	15.28	11.59
Fe ₂ O ₃	5.50	4.29	8.06	5.99	5.57	4.20	3.69	10.50	10.55	5.80
MnO	0.08	0.05	0.15	0.09	0.10	0.04	0.05	0.17	0.14	0.09
MgO	6.82	1.85	8.94	5.12	8.37	1.33	2.29	4.87	9.12	7.96
CaO	4.11	3.14	8.19	5.33	4.07	2.73	3.64	9.06	9.89	4.69
K ₂ O	6.61	3.88	2.66	3.05	3.94	4.72	2.66	4.11	1.31	4.85
Na ₂ O	3.33	3.90	4.48	3.99	4.42	3.79	4.21	4.03	2.86	3.84
P ₂ O ₅	0.41	0.13	0.64	0.18	0.17	0.19	0.12	0.84	0.15	0.41
LOI	0.21	0.26	0.35	0.25	0.74	0.25	0.34	0.47	0.81	0.52
Total	100.84	98.38	99.48	99.83	98.97	99.36	100.00	99.88	99.71	99.52
Sc	7.32	4.54	14.36	8.43	16.63	3.24	6.14	21.15	33.89	3.66
V	25.33	13.59	44.48	30.83	132.09	12.36	14.34	45.32	176.95	15.95
Cr	11.40	12.57	15.97	16.24	79.41	13.57	14.51	74.12	120.10	12.17
Co	9.03	7.01	14.37	9.99	25.49	6.12	8.63	29.43	59.31	5.81
Ni	1.91	2.05	2.42	1.95	16.24	2.83	2.03	21.42	28.82	1.48
Cu	0.20	0.54	0.40	0.26	133.27	0.47	0.56	92.41	101.65	0.15
Zn	19.66	24.25	30.09	18.30	109.77	20.52	34.33	121.74	74.62	14.48
Ga	25.17	20.32	28.47	18.29	31.22	20.20	20.83	32.97	18.62	21.65
Rb	207.37	109.91	125.06	81.78	217.24	108.27	102.87	66.31	36.30	134.64
Sr	882.35	312.37	546.55	581.39	435.49	384.33	313.21	453.69	775.82	676.12
Y	27.47	20.14	74.62	13.11	14.45	30.07	9.65	87.97	19.07	13.50
Zr	392.24	233.93	166.84	65.77	183.10	141.62	138.41	193.87	94.16	255.21
Nb	14.48	9.73	27.41	6.56	10.95	14.41	12.04	26.60	4.23	8.00
Cs	12.27	2.48	4.05	1.57	8.78	4.08	3.08	1.51	0.40	2.21
Ba	1869.46	1026.00	299.91	977.12	575.53	913.24	506.93	1346.00	242.33	666.92
Hf	12.42	7.01	5.98	2.58	4.39	4.62	4.60	3.93	2.14	8.38

Continued

Ta	0.66	0.45	1.08	0.21	1.74	0.92	0.61	3.40	0.52	0.30
Pb	26.70	60.60	24.44	29.98	6.60	32.53	31.50	4.34	5.42	26.09
Th	15.71	13.58	13.31	3.32	2.89	11.88	5.79	0.84	0.50	15.21
U	3.65	3.74	3.51	1.18	0.19	2.80	2.88	0.08	0.04	5.54
La	87.39	55.76	90.81	20.53	17.81	59.87	16.49	64.80	8.48	52.80
Ce	181.47	78.85	213.35	42.96	28.39	122.44	32.77	166.47	20.14	97.61
Pr	19.46	9.36	26.25	5.14	3.72	13.04	3.36	19.05	2.38	10.02
Nd	75.00	34.50	108.00	21.72	19.02	49.67	12.76	104.19	13.66	37.81
Sm	11.89	5.17	20.22	4.16	3.69	8.54	2.34	20.62	3.14	5.86
Eu	2.20	1.49	3.12	0.83	1.32	1.53	0.91	4.12	1.48	1.11
Gd	6.45	3.32	12.48	2.64	3.54	5.43	1.57	18.83	3.55	3.19
Tb	0.85	0.49	1.92	0.37	0.48	0.83	0.24	2.79	0.56	0.41
Dy	4.92	3.02	12.00	2.33	2.34	5.27	1.53	14.40	3.13	2.36
Ho	0.88	0.59	2.33	0.44	0.45	0.94	0.29	2.86	0.62	0.43
Er	2.16	1.51	5.93	1.12	1.31	2.31	0.74	8.39	1.89	1.07
Tm	0.28	0.20	0.79	0.15	0.19	0.29	0.10	1.26	0.32	0.14
Yb	1.83	1.41	5.52	1.02	1.08	1.93	0.68	6.95	1.69	0.94
Lu	0.27	0.21	0.80	0.15	0.17	0.28	0.10	0.99	0.25	0.14
(La/Yb)N	33.09	27.44	11.41	14.00	11.39	1.44	16.80	6.47	1.44	38.96
En/Eu*	0.77	1.10	0.60	0.77	1.12	0.69	1.45	0.64	1.35	0.79
Sr/Y	32.12	15.51	7.32	44.34	30.14	12.78	32.47	5.16	40.69	50.07
Al ₂ O ₃ /TiO ₂	12.10	19.01	7.32	26.20	8.38	18.55	19.75	5.88	15.43	11.25
Na ₂ O/K ₂ O	0.50	1.01	1.68	1.31	1.12	0.80	1.58	0.98	2.18	0.79
K ₂ O/Na ₂ O	1.98	0.99	0.59	0.76	0.89	1.25	0.63	1.02	0.46	1.26
Al ₂ O ₃ /Na ₂ O	3.63	3.27	2.55	3.35	2.84	3.23	3.00	2.92	5.34	3.02
A/CNK	0.60	0.78	0.45	0.68	0.66	0.75	0.77	0.43	0.63	0.58
A/NK	0.96	1.20	1.11	1.35	1.09	1.08	1.29	1.06	2.49	1.00
NK/A	1.05	0.83	0.90	0.74	0.92	0.93	0.78	0.94	0.40	1.00
Seq.	21	22	23	24	25	26	27	28	29	30
Sample	NTB2(D)	NT11(D)	NT(Pm)	H(Pm)	NT6(Fil M)	HA(M)	NTCH1(M)	NTCH2(M)	NTCH2A(M)	NTK1(M)
SiO ₂	53.71	58.45	70.21	70.07	72.48	70.28	71.13	74.16	74.39	67.81
TiO ₂	1.00	0.47	0.30	0.40	0.01	0.35	0.42	0.04	0.33	0.31
Al ₂ O ₃	13.29	11.95	13.20	12.76	13.35	12.59	11.84	13.12	10.68	14.04
Fe ₂ O ₃	5.84	3.90	1.90	2.78	0.53	2.12	2.28	0.61	2.25	2.28
MnO	0.10	0.06	0.02	0.02	0.01	0.02	0.02	0.02	0.03	0.03
MgO	5.59	4.67	0.63	0.79	0.48	0.81	0.83	0.23	0.30	1.86
CaO	9.98	11.40	1.65	0.90	0.34	1.48	1.51	0.76	1.22	2.20
K ₂ O	4.61	3.07	6.77	7.52	5.48	7.04	6.91	5.05	5.01	6.11
Na ₂ O	3.80	4.45	3.76	3.41	5.92	3.63	3.44	4.98	3.72	4.05
P ₂ O ₅	0.43	0.17	0.07	0.13	0.14	0.12	0.13	0.04	0.12	0.12
LOI	0.50	0.21	0.34	1.23	1.51	0.73	0.56	0.39	0.75	0.20
Total	98.85	98.80	98.85	100.01	100.25	99.17	99.07	99.40	98.80	99.01
Sc	14.85	9.44	1.43	3.36	1.18	2.25	3.69	1.73	3.17	3.07
V	85.81	69.72	160.42	145.91	3.26	148.15	146.42	151.78	159.86	14.46

Continued

Cr	48.51	70.29	78.55	68.84	12.15	71.50	76.02	78.13	81.55	14.50
Co	17.00	16.14	2.35	2.96	2.01	2.44	3.53	0.83	1.84	4.22
Ni	13.41	11.40	1.44	1.09	1.59	0.74	1.03	1.07	0.76	1.38
Cu	30.26	144.83	0.34	0.28	0.42	0.20	0.25	0.25	0.20	0.15
Zn	77.41	60.08	24.91	23.34	12.01	24.93	12.51	12.42	10.86	5.55
Ga	29.14	21.02	20.73	22.41	35.98	22.49	19.08	23.83	20.49	19.81
Rb	203.39	93.56	135.32	303.66	565.77	270.66	239.80	257.97	253.99	180.67
Sr	1361.21	669.42	337.32	172.80	39.42	173.95	192.02	36.14	81.62	241.64
Y	32.48	13.24	20.26	13.28	1.30	15.28	14.52	24.84	17.42	11.96
Zr	321.93	88.88	123.32	274.62	17.51	243.61	317.08	53.92	254.63	290.63
Nb	11.24	3.65	11.35	15.06	50.86	12.23	21.44	60.79	18.37	8.19
Cs	9.03	5.86	1.68	1.00	9.04	1.19	1.35	1.38	1.69	7.03
Ba	1714.58	1193.65	727.25	709.47	60.90	609.17	991.64	60.64	407.19	1107.80
Hf	7.21	2.29	4.55	10.28	0.91	9.41	9.80	3.54	8.96	8.66
Ta	2.52	0.79	0.63	0.15	6.42	0.64	0.99	3.56	1.67	0.39
Pb	4.67	8.01	43.12	48.02	28.82	36.41	40.68	44.21	27.28	32.58
Th	5.07	2.40	17.55	55.92	2.04	52.23	36.99	12.73	55.82	17.08
U	0.46	0.38	1.61	5.14	5.44	8.56	12.08	23.32	12.16	3.70
La	66.06	20.38	97.44	86.56	3.12	75.45	72.99	3.35	57.31	45.25
Ce	149.57	43.76	164.93	169.14	4.26	147.46	149.21	9.73	119.99	83.43
Pr	15.61	4.55	16.80	17.71	0.58	15.27	15.35	0.96	12.31	8.05
Nd	79.51	22.83	56.89	62.78	2.18	54.58	54.56	4.26	43.91	27.56
Sm	13.98	4.09	7.71	9.26	0.55	8.00	8.60	2.12	7.42	3.58
Eu	3.34	1.21	1.15	0.95	0.05	1.01	0.63	0.11	0.51	0.64
Gd	10.30	3.33	4.33	4.59	0.33	4.13	4.52	2.43	3.88	2.12
Tb	1.23	0.44	0.59	0.52	0.06	0.49	0.55	0.64	0.54	0.27
Dy	5.54	2.11	3.62	2.52	0.28	2.57	2.78	4.86	3.00	1.73
Ho	0.98	0.41	0.64	0.41	0.04	0.44	0.50	0.92	0.54	0.33
Er	2.86	1.17	1.55	0.95	0.09	1.05	1.22	2.32	1.34	0.84
Tm	0.45	0.19	0.20	0.11	0.01	0.13	0.18	0.33	0.19	0.13
Yb	2.62	1.10	1.28	0.70	0.05	0.83	1.19	2.09	1.23	0.86
Lu	0.40	0.16	0.19	0.10	0.01	0.12	0.17	0.30	0.18	0.13
(La/Yb)N	1.44	12.86	52.66	86.30	43.29	63.30	42.61	1.12	32.28	36.34
En/Eu*	0.85	1.00	0.61	0.45	0.38	0.54	0.31	0.15	0.29	0.71
Sr/Y	41.91	50.54	16.65	13.01	30.36	11.38	13.22	1.45	4.68	20.21
Al ₂ O ₃ /TiO ₂	13.29	25.43	44.00	31.90	1335.00	35.97	28.19	328.00	32.36	45.29
Na ₂ O/K ₂ O	0.82	1.45	0.56	0.45	1.08	0.52	0.50	0.99	0.74	0.66
K ₂ O/Na ₂ O	1.21	0.69	1.80	2.21	0.93	1.94	2.01	1.01	1.35	1.51
Al ₂ O ₃ /Na ₂ O	3.50	2.69	3.51	3.74	2.26	3.47	3.44	2.63	2.87	3.47
A/CNK	0.45	0.38	0.80	0.83	0.82	0.77	0.74	0.87	0.78	0.81
A/NK	1.18	1.12	0.98	0.93	0.85	0.92	0.90	0.96	0.92	1.06
NK/A	0.85	0.89	1.03	1.08	1.17	1.08	1.11	1.04	1.08	0.95

Continued

Seq.	31	32	33	34	35	36	37	38	39	40
Sample	NTK3(M)	C(Um)	D (Um)	NTS1(Um)	NTS1A(Um)	NTS2(Um)	NTC1(Um)	NTC3(Um)	NTC4(Um)	NTCH3 (Um)
SiO ₂	59.12	73.40	69.89	60.00	71.03	71.33	73.08	69.93	71.05	60.63
TiO ₂	1.04	0.35	0.50	1.75	0.66	0.43	0.23	0.44	0.50	1.64
Al ₂ O ₃	14.55	11.04	12.32	12.59	11.72	11.84	11.58	12.44	11.74	11.54
Fe ₂ O ₃	4.38	2.61	2.71	6.59	3.72	3.00	1.77	2.74	3.23	7.64
MnO	0.08	0.03	0.02	0.09	0.03	0.03	0.01	0.02	0.04	0.09
MgO	7.83	0.43	0.97	5.90	0.82	0.70	0.42	0.95	0.79	5.33
CaO	5.54	1.68	2.11	4.50	1.92	1.78	1.03	1.59	1.75	4.70
K ₂ O	3.40	5.81	6.90	5.82	6.99	6.84	7.15	7.14	4.71	4.47
Na ₂ O	4.09	3.33	3.39	3.13	2.92	3.07	3.44	3.33	4.18	2.87
P ₂ O ₅	0.27	0.12	0.16	0.50	0.17	0.12	0.10	0.16	0.15	0.60
LOI	0.35	0.48	0.68	0.65	0.40	0.45	0.40	0.80	0.88	1.58
Total	100.65	99.28	99.65	101.52	100.38	99.59	99.21	99.54	99.02	101.09
Sc	12.36	2.90	3.18	10.87	4.10	3.54	2.73	2.98	3.32	13.81
V	115.14	165.33	158.33	614.85	171.02	147.71	10.48	160.15	152.25	747.64
Cr	61.56	86.03	76.79	371.46	85.64	75.77	17.11	80.39	79.18	451.52
Co	18.80	2.02	2.44	16.70	2.61	2.15	3.87	2.10	2.71	18.67
Ni	14.01	0.78	0.77	8.39	0.82	0.83	1.70	0.76	0.82	8.65
Cu	51.81	0.20	0.20	44.75	0.23	0.21	0.36	0.22	0.21	51.93
Zn	85.73	12.16	12.02	117.36	11.39	11.50	6.44	10.16	14.53	116.60
Ga	26.89	21.85	24.34	26.35	25.30	23.61	19.95	23.30	24.63	29.97
Rb	93.46	237.32	250.70	190.06	244.43	251.63	250.63	250.49	209.53	229.91
Sr	850.12	109.12	183.11	547.27	176.62	147.49	102.35	142.49	132.82	608.18
Y	30.08	13.60	17.64	29.12	30.04	13.93	6.47	12.10	13.13	26.11
Zr	38.23	242.46	263.21	93.20	317.29	299.13	173.46	235.75	273.60	131.17
Nb	5.75	15.69	17.91	16.35	29.15	16.32	19.25	14.26	15.57	13.48
Cs	2.62	1.56	1.42	5.09	3.32	2.59	1.48	1.24	1.02	2.62
Ba	1010.20	660.31	836.04	1193.00	899.10	795.06	282.65	969.21	568.42	1214.06
Hf	0.95	7.82	8.11	2.35	9.70	9.44	6.05	7.60	8.72	2.96
Ta	0.74	1.28	1.30	1.60	2.75	0.98	1.34	1.11	0.78	3.18
Pb	4.23	33.57	31.77	14.99	35.12	31.76	42.95	32.67	34.02	5.64
Th	2.05	40.43	42.08	3.89	46.96	45.76	36.49	41.31	54.45	10.22
U	0.09	4.13	4.34	0.37	6.75	8.75	8.63	4.23	7.63	0.73
La	54.57	63.66	81.98	50.60	114.42	87.30	35.80	66.61	90.00	72.59
Ce	100.09	127.23	164.33	116.92	228.48	177.71	83.58	136.39	180.33	166.92
Pr	10.82	13.12	17.22	12.53	23.73	18.04	9.49	14.09	17.53	17.41
Nd	52.09	46.90	62.23	64.89	86.69	63.66	36.34	50.52	60.28	85.31
Sm	8.46	7.10	9.51	11.64	13.40	9.31	7.93	7.61	8.46	13.26
Eu	2.05	0.64	1.09	2.53	1.25	0.79	0.47	0.84	0.82	2.68
Gd	6.85	3.60	4.80	9.14	7.38	4.62	3.62	3.63	4.02	9.05
Tb	0.89	0.47	0.60	1.16	0.99	0.57	0.37	0.46	0.46	1.06
Dy	4.45	2.60	3.20	5.25	5.45	2.90	1.50	2.48	2.34	4.56

Continued

Ho	0.85	0.44	0.52	0.93	0.93	0.47	0.24	0.39	0.40	0.80
Er	2.56	1.05	1.24	2.50	2.24	1.09	0.55	0.91	0.97	2.24
Tm	0.39	0.14	0.17	0.36	0.31	0.15	0.07	0.12	0.14	0.34
Yb	2.18	0.89	0.99	1.96	1.89	0.89	0.42	0.72	0.88	1.85
Lu	0.31	0.13	0.14	0.28	0.27	0.13	0.06	0.11	0.13	0.26
(La/Yb)N	17.35	49.44	57.26	17.90	42.10	68.41	58.63	63.81	70.86	27.27
En/Eu*	0.83	0.39	0.50	0.75	0.38	0.37	0.27	0.49	0.43	0.75
Sr/Y	28.26	8.02	10.38	18.80	5.88	10.59	15.83	11.77	10.12	23.29
Al ₂ O ₃ /TiO ₂	13.99	31.54	24.64	7.19	17.76	27.53	50.35	28.27	23.48	7.04
Na ₂ O/K ₂ O	1.20	0.57	0.49	0.54	0.42	0.45	0.48	0.47	0.89	0.64
K ₂ O/Na ₂ O	0.83	1.74	2.04	1.86	2.39	2.23	2.08	2.14	1.13	1.56
Al ₂ O ₃ /Na ₂ O	3.56	3.32	3.63	4.02	4.01	3.86	3.37	3.74	2.81	4.02
A/CNK	0.71	0.74	0.73	0.64	0.74	0.75	0.76	0.77	0.77	0.64
A/NK	1.40	0.94	0.94	1.10	0.95	0.95	0.86	0.94	0.98	1.21
NK/A	0.72	1.07	1.06	0.91	1.06	1.05	1.16	1.06	1.02	0.83

anomalies and higher (La/Yb)N value in mylonite (sample NT2). Two types of trend in trace elements distribution, viz. i) depletion of HFSE (Sr, Ta, Nb, Rb, Ba, Y, Hf) and positive anomalies of Cs, Nd, Sm, U and Ti with V-shaped strong negative anomaly of Eu in metagabbro, and ii) enrichment of LIL elements (Rb, K, Sr, Th) and depletion of Nb, Hf, Zr, Rb in the Magba rocks have been also observed (**Figure 14**).

In general, rocks of Eu positive signature have more variation in the HREE and comprise pronounced positive anomalies of Pb and Zr.

The nature of these patterns suggests complex evolution of these rocks, which would have gone through multiple magmatic processes.

5. Discussion

5.1. Petrogenesis

The petrogenesis of magmatic suites generally depends on the tectonic regime in which the parent magmas are generated [31]. The igneous parentage for the protoliths of the Magba rocks is evident from their metaluminous nature (**Figure 10**) and their relatively low K₂O/Na₂O ratios (**Table 2**). In addition, the marked expanded range in composition and in geochemical parameters presented by Magba rocks is typical of dominantly mantle-derived I-type granites, with crustal melt components (e.g. Chappell and White 1974) [32].

The geochemical signature of the Magba granitoids and associated mafic rocks also revealed that they might derive from crustal source rock. Their characteristic depletion in Nb, P, Zr and Ti and also the low concentrations of Co, Ni and Cr is a geochemical feature of calc-alkaline granites of crustal origin. The molar ratio (A/CNK) of almost all the rocks is around 0.38 and 0.78. This ratios place all samples from the study area within the I-type granite field (**Figure 10**). Partial melting experiments on crustal rocks by Roberts and Clemens (1993) [33] suggest that high-K, I-type granitic magmas can be derived from the partial melting of hydrous, calc-alkaline mafic to intermediate meta-igneous rocks in the lower crust.

The hydrous character of such magma derives from the dehydration of altered subducted oceanic lithosphere [34]. The Magba rocks also display relative depletion of Ta, which is indicative of the presence or of residual Ta bearing minerals such as rutile, amphibole, or garnet at the source during partial melting [35]–[37]). The presence of magmatic flow and magmatic myrmekites on Magba granitoids suggest the magmatic origin of rocks rather than a remobilization of adjacent gneisses. Abundance of unaltered microclines nearby altered plagioclases and other exsolution textures indicate that these granites were also subjected to metasomatic reactions [38]. The depletion of HREEs is also suggestive of refractory garnet at the magma source [39].

The near unity of Eu anomalies and the nearly flat HREE patterns for all the magmatic rocks (**Figure 13**) indicate the role of plagioclase in the source residue and imply melting at shallow depths. The low to high La/Yb

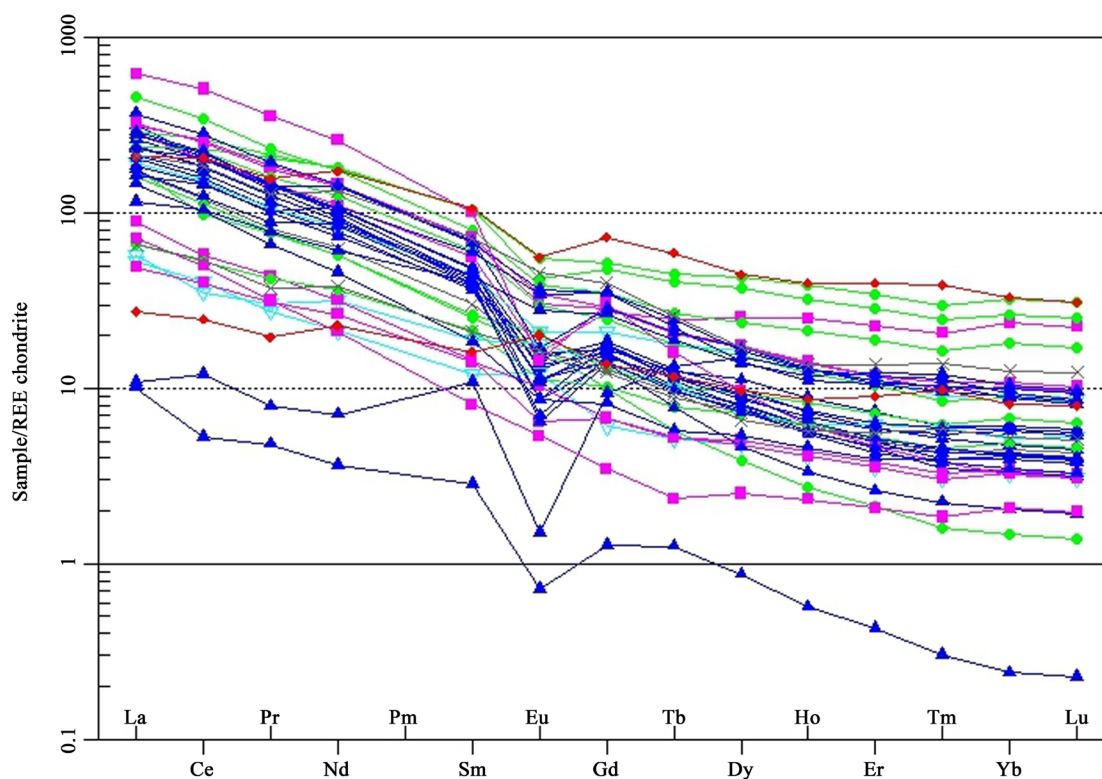


Figure 13. Rare Earth element patterns of sample of Magba rocks. Chondrite normalized Rare Earth Element patterns after Boynton (1984) Symbols are the same as in Figure 9.

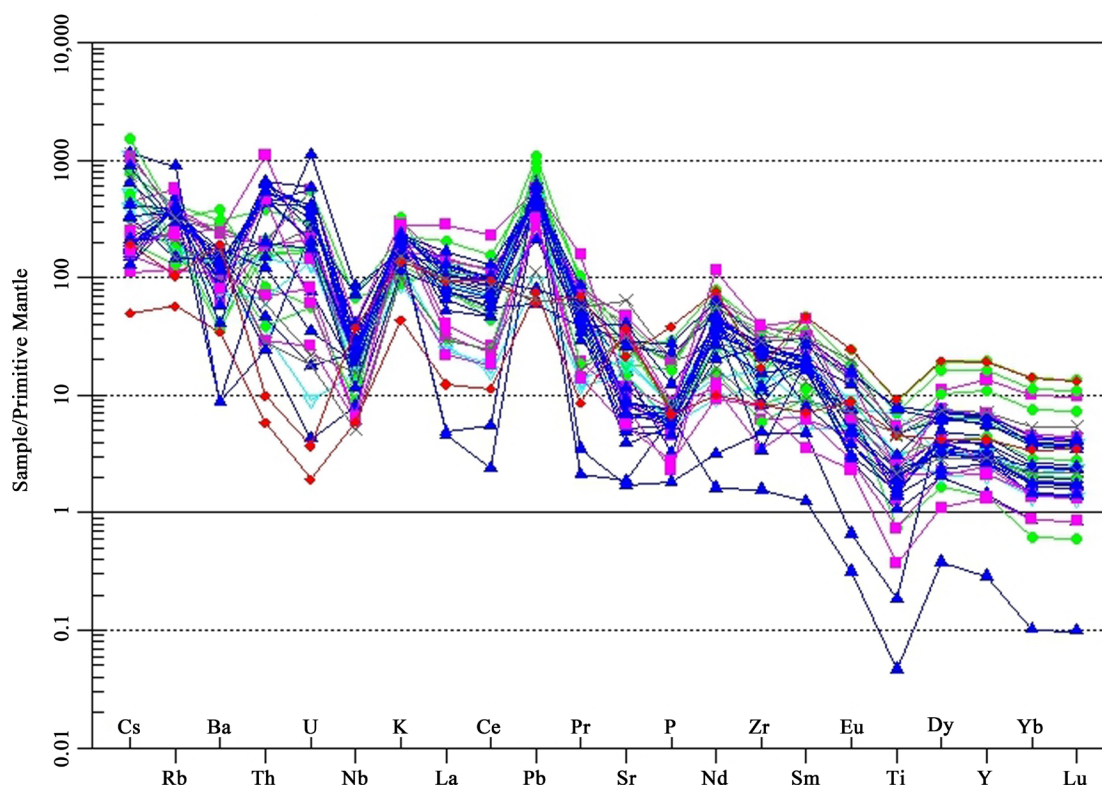


Figure 14. Spider plots of Magba rocks normalized to (Sun and McDonough 1989) Symbols are the same as in Figure 9.

(>20) and Sr/Y (>40) ratios (**Table 2**) for the rocks samples further corroborates the variable depths of melting, probably as deep as the garnet stability field (for those samples with Sr/Y > 40 and La/Yb > 20) and as shallow as to bear the amphibole $\pm$ plagioclase as source components [40] [41].

The evolutionary trend for the granitoids especially the linear variation in CaO, MgO, FeO, TiO₂, and P₂O₅ with increasing SiO₂ content reflects igneous fractionation involving feldspar, biotite, ilmenite and apatite (**Figure 14**). A fractionation process including LREE-rich accessory phase is governed by monazite and apatite in granites, which have a strong affinity for the LREE. HREE depletion observed in the rocks is demonstrated by a flattened to a slightly curved chondrite normalized pattern, which could be attributed to fractionation of zircon or HREE poor source region. Partial melting of hydrated lower crustal rocks rich in residual garnet probably generated this magma.

5.2. Tectonic Setting

In the traditional tectonic discrimination diagram of [42], the rocks of present study are confined to the field of volcanic arc granites (VAG) (**Figure 15**), and are largely situated within the syn-collision to within plate fields.

Major element geochemistry of the Magba rocks reveals high-K calc-alkaline to shoshonitic characteristic similar to granitic rocks that have been described in Pan-African belt in Cameroon, Eastern Nigeria and the bre-siliano belt in Ne brasil [43] [44], indicating a subduction-to collision-related magmatism. The low to high Sr (36.14 - 1361.11 ppm), Y (1.29 - 89.19 ppm) contents and the low contents of Nb and Ta (0.14 - 6.42) in the rocks favour a subduction-related and in some extend a collision-related continental setting. The volcanic arc setting for some samples could be attributed to the tectonic setting of protholith from which it was derived because trace element features of granitic rocks largely depend on their protholith composition [45]. Recent integrated studies on nearest lithologies to Magba rocks (Batouri granitoids) clearly indicate magma derivation in an active convergent margin setting spetially in a subduction-related setting [46]. They suggested that the magmatic suite in the Adamawa Yade domain is a convergent margin setting.

Their high-K, calc-alkaline affinities are also consistent with granitoids formed in active continental margins [42]. These characteristics conform with the geodynamic collision model proposed by [20] for the Pan-African mobile belt in Cameroon. According to this model, the collision between the mobile belt and the northern edge of the Congo Craton resulted in crustal thickening, sub-crustal lithospheric delamination, and upwelling of the asthenosphere.

These processes would have generated excess heat, melted crustal rock at depth, and produced high-K calc-alkaline magmas. Because of the widespread occurrence of granitoids in the AYD with similar chemical features (*i.e.* high-K, calc-alkaline, metaluminous and, I-type affinities), [47] postulated that these granitoids may represent outcrops of a regional-scale batholith underlying the AYD.

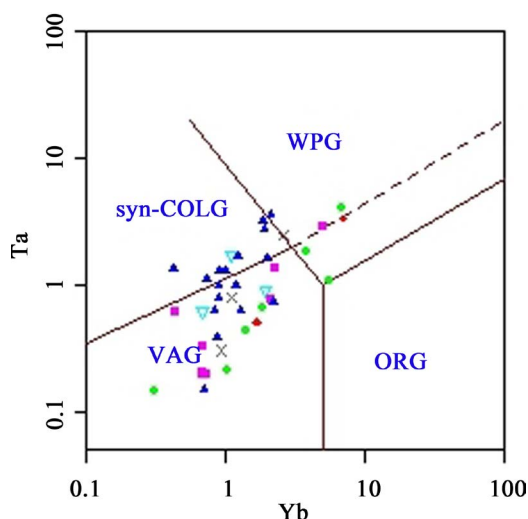


Figure 15. Geotectonic discrimination diagram for Magba rocks after Pearce *et al.* (1984), showing that the rocks were formed in a volcanic arc setting. Symbols are the same as in **Figure 9**. Syn-COLG, syn-collisional granitoid; WPG, within-plate granitoid; VAG, volcanic arc granitoid; ORG, oceanic ridge granitoid.

The syn-collisional to late and post-collisional setting in the Magba rocks is harmonious with results of studies on granitic plutons in the Neoproterozoic fold belt of Cameroon [48], which are inferred to be emplaced during the Pan-african D₂ event. From field and petrographic observations, the rocks show deformational features, which are consistent with their emplacement during tectonic deformation Table 1. This suggests its emplacement during the late or post-collisional phase of the Pan-African orogeny.

6. Conclusions

The aim of this study was to identify the Magba lithologies and their conditions of emplacement. To achieve those objectives, petrography, and geochemistry characterization were necessary. The main results show that Magba zone is made up of granites, orthogneiss, migmatites, metagabbro, mafic dykes and mylonites with porphyritic texture for granites, porphyroblastic to grano-lepido-porphyroblastic texture for orthogneiss, and migmatites, cataclastic texture for mafic dykes and ocellar mylonitic to cataclastic texture for mylonites. Crushing to varying degrees of study area allowed the identification of protomylonites, mylonites and ultramylonites.

Magba granitoids are from magmatic origin and are subjected to metasomatic reactions. Mafic dykes and mylonites indicate firstly that the study area is a shear zone and secondly the primary magmatic intrusive origin for Magba rocks, rather than a remobilization of adjacent gneisses.

The whole rock analyses for major, minor and trace elements of Magba rocks suggest an I-type calc-alkaline magma source in a continental volcanic arc setting. Partial melting of hydrated lower crustal rocks rich in residual garnet probably generated this magma.

The Magba rocks are metaluminous, display high-K, calc-alkaline to shoshonitic affinities and are largely situated within the syn-collision to within plate fields. They show a subduction—to collision-related magmatism and suggest their emplacement during the syn—to post-collisional phase of the Pan-African orogeny.

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References

- [1] Ngako, V., Affaton, P., Nnange, J.M. and Njanko, T. (2003) Panafrican Tectonic Evolution in Central and Southern Cameroon: Transpression and Transtension during Sinistral Shear Movements. *Journal of African Earth Sciences*, **36**, 207-214. [http://dx.doi.org/10.1016/S0899-5362\(03\)00023-X](http://dx.doi.org/10.1016/S0899-5362(03)00023-X)
- [2] Kankeu, B., Greiling, R.O. and Nzenti, J.P. (2009) Pan-African Strike-Slip Tectonics in Eastern Cameroon-Magnetic Fabrics (AMS) and Structure in the Lom Basin and Its Gneissic Basement (Bétaré-Oya Area). *Precambrian Research*, **174**, 258-272. <http://dx.doi.org/10.1016/j.precamres.2009.08.001>
- [3] Njonfang, E., Ngako, V., Kwekam, M. and Affaton, P. (2006) Les orthogneiss calcoal-calins de Foumban-Bankim: Témoins d'une zone interne de marge active panafricaine en cisaillement. *Comptes Rendus Géosciences*, **338**, 606-616. <http://dx.doi.org/10.1016/j.crte.2006.03.016>
- [4] Njonfang, E., Ngako, V., Moreau, C., Affaton, P. and Diot, E. (2008) Restraining Bends in High Temperature Shear Zones: The "Central Cameroon Shear Zone". Central Africa. *Journal of African Earth Sciences*, **52**, 9-20. <http://dx.doi.org/10.1016/j.jafrearsci.2008.03.002>
- [5] Ntiéche, B. (2009) Etude pétrographique et géo-environnementale des granitoïdes de la zone de Magba Ouest Cameroun. DEA Univ. Yaoundé I., 53.
- [6] Toteu, S.F., Van Schmus, W.R., Penaye, J. and Nyobé, J.B. (1994) U-Pb and Sm-Nd Evidence for Eburnian and Pan-African High-Grade Metamorphism in Cratonic Rocks of Southern Cameroon. *Precambrian Research*, **67**, 321-347. [http://dx.doi.org/10.1016/0301-9268\(94\)90014-0](http://dx.doi.org/10.1016/0301-9268(94)90014-0)
- [7] Toteu, S.F., Van Schmus, W.R., Penaye, J. and Michard, A. (2001) New U-Pb and Sm-Nd Data from North-Central Cameroon and Its Bearing on the Pre-Pan African History of Central Africa. *Precambrian Research*, **108**, 45-73. [http://dx.doi.org/10.1016/S0301-9268\(00\)00149-2](http://dx.doi.org/10.1016/S0301-9268(00)00149-2)
- [8] Basseka, C.A., Shandini, Y. and Tadjou, J.M. (2011) Sub-Surface Structural Mapping Using Gravity Data of the Northern Edge of the Congo Craton, South Cameroon. *Geofizika*, **28**, 229-245.
- [9] Tchameni, R., Mezger, K., Nsifa, N.E. and Pouclet, A. (2001) Crustal Origin of Early Proterozoic Syenites in the Congo Craton (Ntem Complex), South Cameroon. *Lithos*, **57**, 23-42.

- [http://dx.doi.org/10.1016/S0024-4937\(00\)00072-4](http://dx.doi.org/10.1016/S0024-4937(00)00072-4)
- [10] Tanko, N.E.L., Nzenti, J.P., Njanko, T., Kapajika, B. and Nédélec, A. (2005) New U-Pb Zircon Ages from Tonga (Cameroon): Coexisting Eburnean-Transamazonian (2.1 Ga) and Pan-African (0.6 Ga) Imprints. *Comptes Rendus Geoscience*, **337**, 551-562. <http://dx.doi.org/10.1016/j.crte.2005.02.005>
 - [11] Shang, C., Satir, M., Nsifa, E., Liégeois, J.P., Siebel, W. and Taubald, H. (2007) Archean High-K Granitoids Produced by Remelting of Earlier Tonalite Trondhjemite-Granodiorite (TTG) in the Sangmelima Region of the Ntem Complex of the Congo Craton, Southern Cameroon. *International Journal of Earth Sciences*, **96**, 817-841. <http://dx.doi.org/10.1007/s00531-006-0141-3>
 - [12] Van Schmus, W.R., Oliveira, E.P., Da Silva Filho, A.F., Toteu, S.F., Penaye, J. and Guimaraes, I.P. (2008) Proterozoic Links between the Borborema Province, NE Brazil, and the Central African Fold Belt. *Geological Society, London, Special Publications*, **294**, 69-99. <http://dx.doi.org/10.1144/SP294.5>
 - [13] Nédélec, A., Nsifa, E.N. and Martin, H. (1990) Major and Trace Element Geochemistry of the Archean Ntem Plutonic Complex (South Cameroon): Petrogenesis and Crustal Evolution. *Precambrian Research*, **47**, 35-50. [http://dx.doi.org/10.1016/0301-9268\(90\)90029-P](http://dx.doi.org/10.1016/0301-9268(90)90029-P)
 - [14] Shang, C.K., Satir, M., Siebel, W., Nsifa, E.N., Taubald, H., Liégeois, J.P. and Tchoua, F.M. (2004) TTG Magmatism in the Congo Craton; a View from Major and Trace Element Geochemistry, Rb-Sr and Sm-Nd Systematics: Case of the Sangmelima Region, Ntem Complex, Southern Cameroon. *Journal of African Earth Sciences*, **40**, 61-79. <http://dx.doi.org/10.1016/j.jafrearsci.2004.07.005>
 - [15] Suh, C.E., Cabral, A.R., Shemang, E.M., Mbinkar, L. and Mboudou, G.G.M. (2008) Two Contrasting Iron Deposits in the Precambrian Mineral Belt of Cameroon, West Africa. *Exploration and Mining Geology*, **17**, 197-207. <http://dx.doi.org/10.2113/gsemg.17.3-4.197>
 - [16] Feybesse, J.L., Johan, V., Triboulet, C., Guerrot, C., Mayaga-Mikolo, F., Bouchot, V. and Eko N'dong, J. (1998) The West Central African Belt: A Model of 2.5-2.0 Ga Accretion and Two-Phase Orogenic Evolution. *Precambrian Research*, **87**, 161-216. [http://dx.doi.org/10.1016/S0301-9268\(97\)00053-3](http://dx.doi.org/10.1016/S0301-9268(97)00053-3)
 - [17] Penaye, J., Toteu, S.F., Tchameni, R., Van Schmus, W.R., Tchakounté, J., Ganwa, A., Minyem, D. and Nsifa, E.N. (2004) The 2.1 Ga West Central African Belt in Cameroon: Extension and Evolution. *Journal of African Earth Sciences*, **39**, 159-164. <http://dx.doi.org/10.1016/j.jafrearsci.2004.07.053>
 - [18] Lerouge, C., Cocherie, A., Toteu, S.F., Penaye, J., Milési, J.P., Tchameni, R., Nsifa, E.N., Mark Fanning, C. and Deloule, E. (2006) Shrimp U-Pb Zircon Age Evidence for Paleoproterozoic Sedimentation and 2.05 Ga Syntectonic Plutonism in the Nyong Group, South-Western Cameroon: Consequences for the Eburnean-Transamazonian Belt of NE Brazil and Central Africa. *Journal of African Earth Sciences*, **44**, 413-427. <http://dx.doi.org/10.1016/j.jafrearsci.2005.11.010>
 - [19] Toteu, S.F., Van Schmus, W.R. and Penaye, J. (2006) The Precambrian of Central Africa: Summary and Perspectives. *Journal of African Earth Sciences*, **44**, 7-10. <http://dx.doi.org/10.1016/j.jafrearsci.2005.12.002>
 - [20] Toteu, S.F., Penaye, J. and Djomani, Y.P. (2004) Geodynamic Evolution of the Pan-African Belt in Central Africa with Special Reference to Cameroon. *Canadian Journal of Earth Sciences*, **41**, 73-85. <http://dx.doi.org/10.1139/e03-079>
 - [21] Toteu, S.F., Penaye, J., Deloule, E., Van Schmus, W.R. and Tchameni, R. (2006) Diachronous Evolution of Volcano-sedimentary Basins North of the Congo Craton: Insights from U-Pb Ion Microprobe Dating of Zircons from the Poli, Lom and Yaoundé Groups (Cameroon). *Journal of African Earth Sciences*, **44**, 428-442. <http://dx.doi.org/10.1016/j.jafrearsci.2005.11.011>
 - [22] Nzenti, J.P., Barbey, P., Macaudiere, J. and Soba, D. (1988) Origin and Evolution of the Late Precambrian High-Grade Yaoundé Gneisses (Cameroon). *Precambrian Research*, **38**, 91-109. [http://dx.doi.org/10.1016/0301-9268\(88\)90086-1](http://dx.doi.org/10.1016/0301-9268(88)90086-1)
 - [23] Moreau, C., Regnault, J.-M., Deruelle, B. and Robineau, B. (1987) A New Tectonic Model for the Cameroon Line, Central Africa. *Tectonophysics*, **139**, 317-334. [http://dx.doi.org/10.1016/0040-1951\(87\)90206-X](http://dx.doi.org/10.1016/0040-1951(87)90206-X)
 - [24] Krishna, A.K., Murthy, N.N. and Govil, K. (2007) Multielement Analysis of Soils by Wavelength-Dispersive X-Ray Fluorescence Spectrometry. *Atomic Spectroscopy*, **28**, 202-214.
 - [25] Balaram and Rao, T.G. (2003) Rapid Determination of REE and Other Trace Elements in Geological Samples by Microwave Acid Digestion and ICP-MS. *Atomic Spectroscopy*, **24**, 206-212.
 - [26] Middlemost, E.A.K. (1977) *Magmas, Rocks and Planetary Development*. Longman, Harlow.
 - [27] Chappell, B.W. and White, A.J.R. (1992) I- and S-Type Granites in the Lachlan Fold Belt. *Transactions of the Royal Society of Edinburgh: Earth and Environmental Science*, **83**, 1-26. <http://dx.doi.org/10.1017/S0263593300007720>
 - [28] Peccerillo, A. and Taylor, S.R. (1976) Geochemistry of Eocene Calc-Alkaline Volcanic Rocks from the Kastamonu Area, Northern Turkey. *Contributions to Mineralogy and Petrology*, **58**, 63-81. <http://dx.doi.org/10.1007/BF00384745>
 - [29] Boynton, W.V. (1984) Geochemistry of the Rare Earth Elements: Meteorite Studies. In: Henderson, P., Ed., *Rare*

- Earth Element Geochemistry*, Elsevier, Amsterdam, 63-114. <http://dx.doi.org/10.1016/B978-0-444-42148-7.50008-3>
- [30] Sun, S. and McDonough, W. (1989) Chemical and Isotopic Systematic of Oceanic Basalts: Implications for Mantle Composition and Processes. *Special Publication of Geological Society of London*, **42**, 313-345. <http://dx.doi.org/10.1144/GSL.SP.1989.042.01.19>
- [31] Santosh, M., Qiong-Yan, Y., Shaji, E., Mohan, M.R., Tsunoga, T. and Satyanarayanan, M. (2014) Oldest Rocks from Peninsular India: Evidence for Hadean to Neoproterozoic Crustal Evolution. *Gondwana Research*.
- [32] Chappell, B.W. and White, A.J.R. (1974) Two Contrasting Granite Types. *Pacific Geology*, **8**, 173-174.
- [33] Roberts, M.P. and Clemens, J.D. (1993) Origin of High-Potassium, Talc-Alkaline, I-Type Granitoids. *Geology*, **21**, 825-828. [http://dx.doi.org/10.1130/0091-7613\(1993\)021<0825:OOHPTA>2.3.CO;2](http://dx.doi.org/10.1130/0091-7613(1993)021<0825:OOHPTA>2.3.CO;2)
- [34] Ulmer, P. (2001) Partial Melting in the Mantle Wedge—The Role of H₂O in the Genesis of Mantle-Derived ‘Arc-Related’ Magmas. *Physics of the Earth and Planetary Interiors*, **127**, 215-232. [http://dx.doi.org/10.1016/S0031-9201\(01\)00229-1](http://dx.doi.org/10.1016/S0031-9201(01)00229-1)
- [35] Green, T.H. and Pearson, N.J. (1986) Ti-Rich Accessory Phase Saturation in Hydrous Mafic-Felsic Compositions at High P, T. *Chemical Geology*, **54**, 185-201. [http://dx.doi.org/10.1016/0009-2541\(86\)90136-1](http://dx.doi.org/10.1016/0009-2541(86)90136-1)
- [36] Wilson, M. (1989) *Igneous Petrogenesis*. Unwin Hyman, London, 450 p. <http://dx.doi.org/10.1007/978-1-4020-6788-4>
- [37] De Souza, Z.S., Martin, H., Peucat, J.J., De Sa, E.F.J. and Macedo, M.H.D.F. (2007) Calcalkaline Magmatism at the Archean Proterozoic Transition: The Caico Complex Basement (NE Brazil). *Journal of Petrology*, **48**, 2149-2185. <http://dx.doi.org/10.1093/petrology/egm055>
- [38] Weecksteen, G. (1954) Les massifs volcaniques du pays Bamoun. Rapport annuel serv. Géol. Cameroun, 61-66.
- [39] Rollinson, H.R. (1993) *Using Geochemical Data: Evaluation, Presentation, Interpretation*. Pearson Education Limited, Geochemistry Series, Essex, 352 p.
- [40] Mohan, M.R., Piercey, S.J., Kamber, B.S. and Sarma, D.S. (2013) Subduction Related Tectonic Evolution of the Neoproterozoic Eastern Dharwar Craton, Southern India: New Geochemical and Isotopic Constraints. *Precambrian Research*, **227**, 204-226. <http://dx.doi.org/10.1016/j.precamres.2012.06.012>
- [41] Moyen, J.-F. (2009) High Sr/Y and La/Yb Ratios: The Meaning of the “Adakitic Signature”. *Lithos*, **112**, 556-574. <http://dx.doi.org/10.1016/j.lithos.2009.04.001>
- [42] Pearce, J.A., Harris, N.B.W. and Tindle, A.G. (1984) Trace Element Discrimination Diagrams for the Tectonic Interpretation of Granitic Rocks. *Journal of Petrology*, **25**, 956-983. <http://dx.doi.org/10.1093/petrology/25.4.956>
- [43] Kouankap, N.G.D., Nzenti, J.P., Suh Cheo, E. and Ganno, S. (2010) Geochemistry of Ferriferous, High-K Calc-Alkaline Magmas from the Banefo-Mvoutsaha Massif (NE Bafoussam), Central Domain of the Pan-African Fold Belt, Cameroon. *The Open Geology Journal*, **4**, 15-28. <http://dx.doi.org/10.2174/1874262901004010015>
- [44] Ferré, E., Caby, R., Peucat, J.J., Capdevila, R. and Monié, P. (1998) Pan-African, Post-Collisional, Ferro-Potassic Granite and Quartz-Monzonite Plutons of Eastern Nigeria. *Lithos*, **45**, 255-279. [http://dx.doi.org/10.1016/S0024-4937\(98\)00035-8](http://dx.doi.org/10.1016/S0024-4937(98)00035-8)
- [45] Altherr, F.F., Holl, A., Hegner, E., Langer, C. and Kreuzer, H. (2000) High-Potassium, Calc-Alkaline I-Type Plutonism in the European Variscides: Northern Vosges (France) and Northern Schwarzwald (Germany). *Lithos*, **50**, 51-73. [http://dx.doi.org/10.1016/S0024-4937\(99\)00052-3](http://dx.doi.org/10.1016/S0024-4937(99)00052-3)
- [46] Akwanga, A., Basem, Z., Bernd, L., Dirk, F., Ray, B. and Cheo, E.S. (2015) Geochemistry and Geochronology of the ~620 Ma Gold-Associated Batouri Granitoids, Cameroon. *International Geology Review*, **57**, 1485-1509.
- [47] Tchameni, R., Poulet, A., Penaye, J., Ganwa, A.A. and Toteu, S.F. (2006) Petrography and Geochemistry of the Ngaoundéré Pan-African granitoids in Central North Cameroon: Implications for Their Sources and Geological Setting. *Journal of African Earth Sciences*, **44**, 511-529. <http://dx.doi.org/10.1016/j.jafrearsci.2005.11.017>
- [48] Tagne-Kamga, G. (2003) Petrogenesis of the Neoproterozoic Ngondo Plutonic Complex West Cameroon Central Africa): A Case of Late-Collisional Ferropotassic Magmatism. *Journal of African Earth Sciences*, **36**, 149-171. [http://dx.doi.org/10.1016/S0899-5362\(03\)00043-5](http://dx.doi.org/10.1016/S0899-5362(03)00043-5)



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