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**The geologic record of the exhumed root of the Central African Orogenic Belt in the
Central Cameroon Domain (Mbé – Sassa-Mbersi region)**

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Abstract

We present structural, petrological, geochemical and geochronological data compiled in a new geological map on the high-grade metamorphic rocks exposed in the Mbé – Sassa-Mbersi region located along the Tcholliré-Banyo Shear Zone, at the northern edge of the Central Cameroon domain.

The region exposes a complex assemblage of metabasic (hornblendite, metagabbro, amphibolite) and metasedimentary (garnet paragneiss, calc-silicate gneiss) rocks alternating with ubiquitous migmatitic intermediate to felsic gneisses. U-Pb ages on detrital zircon in paragneiss point to the contribution of Archean, Paleoproterozoic and Neoproterozoic sources, and suggest a maximum deposition age of 725 ± 12 Ma. The protolith of some amphibolites was emplaced during the Neoproterozoic as indicated by U-Pb ages on magmatic zircon at 600 ± 4 and 599 ± 6 Ma. Plutonic rocks with I-type chemical signatures were emplaced discontinuously over a period of ca. 80 Ma. The magmatic evolution started with the intrusion of magnesian medium-K tonalites and trondhjemites at 651 ± 3 Ma, followed by magnesian high-K hornblende-biotite granites and ferroan shoshonitic biotite granites until 599 ± 2 Ma. Finally, pegmatite dykes were emplaced along dextral shear zones at 573 ± 2 Ma. The metamorphic rocks show a penetrative shallow-dipping foliation partially to totally transposed in a NE-SW trending steep-dipping foliation bearing a shallow-dipping lineation. These ductile syn-migmatitic fabrics, developed under high-grade metamorphic conditions in the presence of melt, between the metamorphic peak at ca. 1.3 GPa – 770 °C, and the following isothermal decompression down to ca. 0.8 GPa. In situ U-Pb dating of metamorphic zircon rims yields an age of 582 ± 4 Ma. Localization of high-grade deformation is indicated by the development of the Tcholliré-Banyo Shear Zone, characterized by mutually crosscutting subvertical and shallow-dipping mylonitic to ultramylonitic shear zones associated with sinistral and top-to-the SW kinematic criteria, respectively. These data indicate that the Central Cameroon domain exposed in the Mbé – Sassa-Mbersi region, represents the exhumed mid- to lower part of the former orogenic root of the Pan-African Central Africa Orogenic Belt that has undergone partial melting, lateral flow and intrusion of mafic to felsic calc-alkaline magmas between 650 and 580 Ma. The waning stage of the Pan-African orogeny is marked by the emplacement of syntectonic pegmatitic granite at ca. 575 Ma in subvertical E-W trending retrogressive dextral shear zones.

Keywords: West Gondwana; Pan-African; Central Africa Orogenic Belt; Cameroon; Orogenic root

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55 **Highlights:**

- 56 • The Central Cameroon domain is made of Pan-African metamorphic/plutonic rocks
- 57 • The youngest protolith of metasedimentary rocks were deposited at <725 Ma
- 58 • Plutonic rocks with calc-alkaline signatures emplaced between ca. 650 and 575 Ma
- 59 • High-grade metamorphism (1.3 GPa – 770°C) occurred at >580 Ma
- 60 • Deformation records lateral flow of the partially molten orogenic root of the CAfOB

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1. Introduction

The Central African Orogenic Belt (CAfOB, [Fig. 1](#)), also designated as the North Equatorial Mobile Belt, or the Central African Fold Belt, is pinched between the Congo Craton, the West African Craton and the enigmatic Sahara Metacraton ([Bessoles and Trompette, 1980](#); [Nzenti et al., 1988](#); [Abdelsalam et al., 2002](#); [Toteu et al., 2004](#); [Van Schmus et al., 2008](#)). Geodynamic models proposed for the tectonic-magmatic evolution of the Central African Orogenic Belt differ in terms of the nature of the geologic domains involved and on the sources of magmatic rocks ([Castaing et al., 1994](#); [Nzenti et al., 1994, 1999](#); [Abdelsalam et al., 2002](#); [Ngako et al., 2003, 2008](#); [Toteu et al., 2004](#); [Penaye et al., 2006](#); [Kwekam et al., 2010](#); [Liégeois et al., 2013](#); [Isseini et al., 2012](#); [Nkoumbou et al., 2014](#); [Tchakounté et al., 2017](#)). At one end of the spectrum, some authors favour the impact of reworking of cratonic margins during the Pan-African orogeny as a result of inversion of continental to oceanic rifts followed by collision and indentation between the cratonic continental blocks (the “crustal reworking model” [Fig. 2a](#)). At the other end of the spectrum, other authors argue for a dominant magmatic accretion along an active margin (the northern margin of the Congo craton) punctuated by tectonic accretion of continental ribbons and rift basins associated with southward subduction (the “magmatic-tectonic accretion” model, [Fig. 2b](#)). These discrepancies arise essentially from contrasting interpretation of (i) the nature of the protoliths of ubiquitous migmatitic gneisses, (ii) the impact of Pan-African metamorphism and deformation relative to pre-Neoproterozoic inheritance, and (iii) the sources and petrogenetic context of widespread calc-alkaline to alkaline plutons. In the crustal reworking model, most of the magmatic activity is attributed to crustal partial melting, whereas in the magmatic-tectonic accretion model, at least part of the magmatic rocks with a calc-alkaline signature are assigned a mantle origin.

This debate is in particular nourished by the interpretation of the geological record of Cameroon ([Toteu et al., 2004](#)), which comprises from south to north ([Fig. 1](#)): (i) the South Cameroon domain with the Yaoundé nappe essentially made of Neoproterozoic sediments affected by partial melting under granulite facies dated at about 620-610 Ma and overthrusting the margin of the Congo craton ([Nzenti et al., 1988](#); [Barbey et al., 1990](#); [Penaye et al., 1993](#); [Toteu et al., 1994, 2006a](#); [Mvondo et al., 2007](#); [Owona et al., 2011](#); [Nkoumbou et al., 2014](#)); (ii) the Central Cameroon domain (also designated as the Adamawa-Yade domain) dominated by migmatitic gneisses, amphibolites, granites and some low-grade metavolcanic rocks and

schists (Penaye et al., 1989; Toteu et al., 2001; Ganwa et al., 2011; Bouyo et al., 2013;) and interpreted either as the northern margin of the Congo craton (Kwékam et al., 2010) or as a piece of Archaean crust detached from the Congo Craton (Tchakounté et al., 2017); and (iii) the North Cameroon domain (West Cameroon domain for some authors) comprising the Poli-Zalbi-Goueygoudoum greenstone belt (Bouyo et al., 2015, 2016) intruded by the Mayo-Kebbi – Sinassi calc-alkaline batholith interpreted as an early Pan-African magmatic arc active from ca. 680 to 660 Ma (Pouclet et al., 2006; Isseini et al., 2012) and high-grade gneisses at the lowest structural level (Toteu et al., 2001). The North and Central domains are separated by the Tcholliré-Banyo Shear Zone and the Central and South domains by the Sanaga Shear Zone (Fig. 1; Toteu et al., 2001).

The presence of a Paleoproterozoic basement has been advocated in the Central African Orogenic Belt on the basis of U–Pb ages on zircon at ca. 2.0 Ga (Toteu et al., 1987; Penaye et al., 1989) and Pan-African reworking has been first identified by widespread Neoproterozoic Rb/Sr ages (Lasserre, 1967; Bessoles and Trompette, 1980). In addition, ages obtained on zircon and monazite grains from orthogneisses and granites (ca. 680–570 Ma) point to the intrusion of Pan-African syn- to late-tectonic plutons in the Central Cameroon domain to the north of Ngaoundéré (Toteu et al., 2001; Tchameni et al., 2006). The NE–SW trending sinistral Tcholliré-Banyo Shear Zone (TBSZ) is interpreted to represent the suture between terranes dominated by reworked Archaean to Palaeoproterozoic basement of the margin of the Congo craton and the Western Cameroon domain with a Neoproterozoic juvenile signature (Pinna et al., 1994; Toteu et al., 2001, 2004; Nomo et al., 2017).

In this paper, we complement these previous studies by the presentation of new structural, petrologic-geochemical, and geochronological data on the high-grade metamorphic and plutonic rocks exposed in the Mbé – Sassa-Mbersi region, which is situated at the northern edge of the Central Cameroon domain, along the TBSZ between the towns of Tcholliré and Banyo, about 60 km north of the Ngaoundéré city (Fig. 3). These data are used to discuss the pre-Neoproterozoic heritage, the impact of Pan-African reworking and the geodynamic context accounting for the reconstructed tectonic-magmatic history of this area.

2. Geological setting and debated issues regarding the Central Cameroon domain

The tectonic-metamorphic history of the Central Cameroon domain has been subdivided into distinct phases based on structural analysis and geochronological data (Toteu et al., 2001; Toteu et al., 2004; Ngako et al., 2008; Ngako and Njonfang, 2011). The D₁ phase is characterized by a shallow-dipping syn-migmatitic foliation that has been attributed to east-verging emplacement of nappes. The D₂ phase corresponds to transposition of the shallow-dipping foliation in steep-dipping conjugate shear zones and upright folds leading to the development of the main foliation with a dominant NE-SW trend recording NW-SE regional shortening. The D₁ and D₂ phases have been dated from ca. 635 to ca. 615 Ma by applying U-Pb techniques on zircon from a variety of syntectonic plutonic rocks, and it has been proposed to group them into a single phase of crustal thickening (Ngako and Njonfang, 2011). The D₃ phase is related to strain localization along N-S to NE-SW sinistral shear zones, such as the Banyo-Tcholliré Shear Zone and the D₄ phase corresponds to retrogression associated with activation of NNE-SSW to E-W trending dextral shear zones such as the Central Cameroon Shear Zone. Deformation along the Tcholliré-Banyo Shear Zone was initially suggested to have occurred between ca. 600 and ca. 580 Ma based on U-Pb dating of zircon grains in syntectonic plutons (Penaye et al., 1989; Toteu et al., 2001). However, recently published U-Pb zircon ages of syn-tectonic plutons emplaced in the Tcholliré region suggest an earlier start of deformation at 650 Ma to ca. 630 Ma (Nomo et al., 2017). Inherited zircon cores in these synkinematic granites, yielding late Paleoproterozoic and early Neoproterozoic ages, indicate that the plutonic rocks were formed by the reworking of older crust. The activity of the dextral NNE-SSW to E-W trending dextral shear zones crosscutting the Central Cameroon domain is ill constrained but appears to predate the emplacement of post-tectonic alkaline plutons at ca. 545 Ma, which is consistent with Rb/Sr ages at ca. 540 Ma in this area (Bessoles and Trompette, 1980). Activation of these transcurrent shear zones has been attributed to a transpressive kinematic regime during the late-evolution of the Pan-African orogeny (Ngako et al., 2003; Ngako and Njonfang, 2011).

In the Central Cameroon domain, it was first proposed that granulite-facies mineral relicts in the ortho- and para-gneisses correspond to an Eburnean metamorphism affecting the Paleoproterozoic basement and that Pan-African reworking is only expressed by retrogression under amphibolite facies (Penaye et al., 1989; 2004; Ngako et al., 1990; Toteu, 2001; 2004; Tchakounté et al., 2017). Alternatively, Bouyo Houketchang et al. (2009) and Bouyo et al. (2013) have dated granulite facies metamorphism at ca. 600 Ma, coeval with the development of a shallow-dipping foliation, and have argued that it records crustal thickening owing to

Pan-African continental collision followed by retrogression into amphibolite facies during exhumation.

The Central Cameroon Domain is also marked by the emplacement of magmatic rocks during the Pan-African orogeny that display a variety of petrological and geochemical signatures. Plutonic rocks consist of diorite, tonalite, trondhjemite, granodiorite and granite (Ganwa et al., 2008; Naïmou et al., 2014; Njanko et al., 2006; Tchameni et al., 2006; Toteu et al., 2001, 2004). They have been dated from ca. 640 to 570 Ma and their calc-alkaline signatures, to high-K calc-alkaline for the youngest ones, have been attributed to mixing between a juvenile source and magmas issued from partial melting of Archean to Paleoproterozoic crust (Tchameni et al., 2006; Kwékam et al., 2010; Mbassa et al., 2016; Tchakounté et al., 2017). With regard to the juvenile source, two propositions have been made. Tchameni et al. (2006) propose that it corresponds to an enriched mantle and Kwékam et al. (2010) invoke partial melting triggered by post-collisional delamination of the subcontinental lithospheric mantle. In contrast, Mbassa et al. (2016) favour partial melting of Neoproterozoic oceanic crust tectonically accreted with the continental terranes.

3. Lithological units and main structures of the Mbé – Sassa-Mbersi region

Pioneer geological maps of the Mbé – Sassa-Mbersi region have been completed in the 50's and 60's (Koch, 1953; Guiraudie, 1955; Lasserre, 1961). These authors have proposed to distinguish, within the Precambrian rocks, (i) a basement composed of amphibole-garnet gneisses forming a NE–SW trending belt exposed along the Benue river bed across the Mbé town, and (ii) intrusive rocks represented by more or less deformed diorites, orthogneisses and granites to the East of this belt.

In this section, we present new data collected for the Mbé – Sassa-Mbersi region starting with a refined geological map for this area elaborated on the basis of more than a month of fieldwork (Fig. 3). Outcrops are dispersed but some nice exposures along the Benue riverbed near Ndong Benue and Ndom (Fig. 4), or in quarries such as in Karna, allow the characterization of the main lithological units, metamorphic facies and structural trends of the area (Figs. 5-12). Building on previous subdivisions proposed for the Mbé – Sassa-Mbersi region, we distinguish (i) metabasic rocks (amphibolites, hornblendites and metagabbros), (ii) paragneisses and calc-silicate gneiss, (iii) heterogeneous, migmatitic gneisses and

heterogeneous granitoids with an intermediate to felsic composition, and (iv) monzodioritic to granitic plutons and dikes more or less affected by solid-state deformation (Fig. 5). Note that the previously defined “reworked Paleoproterozoic gneisses” correspond to metabasic and metasedimentary-metavolcanic rocks depicted in the new map presented in this paper, and that orthogneisses and syn- to post-tectonic granites of previous authors match the migmatitic gneisses and plutonic rocks defined in this paper. Contacts between these lithologies are typically transposed in the regional foliation (Fig. 5a to c) but intrusive contacts of the migmatitic intermediate to felsic gneisses into the amphibolites are locally preserved (Fig. 5d) and some dikes are only partially transposed (Fig. 5e).

The dominant structure is a NE–SW trending amphibolite to granulite facies foliation, which transposes the shallow-dipping foliation of metabasic rocks, paragneisses, intermediate to felsic gneisses and the intrusive contacts of plutonic rocks (Fig. 5a to e). The extreme expression of this transposition is the sinistral NE–SW trending Tcholliré-Banyo Shear Zone, delimiting the studied area to the NW. This high-temperature foliation is crosscut by dextral E–W trending mylonitic shear zones associated with retrogression into greenschist facies metamorphism (Fig. 5f).

The description of the geology of the Mbé – Sassa-Mbersi region is complemented in the next sections by petrography of the main lithological units at the outcrop scale (Figs. 6-12) and at the microscopic scale (Fig. 13).

3.1. Metabasic rocks

Metabasic rocks cover the most part of the studied area and are particularly well exposed along the Benue River near the villages of Ndom, Karna and Ndong Benue (Fig. 6). The metabasic rocks are characterized by a composite $S_{0/n}$ foliation transposed in the S_{n+1} schistosity. They locally display centimetre size plagioclase-rich leucosome pockets and veins containing garnet (Fig. 6a). Boudinaged metabasic rocks are ubiquitous with necks filled by plagioclase-rich veins indicating that deformation occurred in the presence of melt. The metabasic rocks correspond to a complex association of hornblendite (NB14-05, NB14-44, ML14-08; Fig. 13a), metagabbro (NB14-11b, NB14-07a and NB14-11c), amphibolite (NB14-11d, ML14-01a, ML14-04, NB14-11e, N14-01a-2, N14-01a-1; Fig. 13b) and garnet amphibolites (ML14-01b, NB14-11a, NB14-08c, NB14-08b, NB14-10; Fig. 13c). The main

mineral phase in all these rocks is amphibole, with composition encompassing the fields of tschermakite, magnesio-hornblende and actinolite; X_{Mg} values range from 0.49 to 0.81, the highest values being observed in hornblendites. Depending on samples, additional mineral phases may be clinopyroxene ($Wo_{49-50}En_{37-39}Fs_{11-13}$), garnet ($Alm_{54-59}Prp_{19-21}Grs_{19-22}Sps_2$), plagioclase ($An_{\leq 25}$), biotite; minor phases are apatite, titanite and quartz; secondary phases are epidote, calcite, chlorite, prehnite and sericite.

3.2. *Paragneisses and calc-silicate gneiss*

Paragneisses form a more or less continuous several kilometre-wide band trending parallel to the NE–SW Banyo-Tcholliré Shear Zone (Fig. 3). They comprise medium-grained garnet gneiss (NB14-01a, NB14-02, NB14-26ab, MM14-01) containing thin bands of fine-grained garnet gneiss (NB14-01b), felsic gneiss (N14-01c) and calc-silicate gneiss (NB14-27a, b). Lithologic alternations underline the inherited bedding transposed into a relatively shallow-dipping foliation designated as $S_{0/n}$. The $S_{0/n}$ foliation is partially to totally transposed into a S_{n+1} foliation in axial planar position of asymmetric folds with variably dipping axes (Fig. 7a). Transposition is associated with the development of a C/S fabric consistent with a sinistral sense of shear (Fig. 7b). The garnet gneiss is migmatitic as expressed by centimetre-thick leucosomes that are folded with the $S_{0/n}$ foliation (Fig. 7c) and form a network of pockets and veins concordant-discordant to the S_{n+1} foliation (Fig. 7d).

Observation under the microscope reveals that garnet gneiss, the most abundant rock type, is made up of quartz, plagioclase (An_{25-35}), minor K-feldspar, biotite ($0.50 \leq X_{Mg} \leq 0.69$), garnet ($Alm_{58-71}Prp_{24-36}Sps_{\leq 3}Grs_{\leq 7}$), with or without kyanite and sillimanite. When present, both Al-silicate phases are encountered in a same thin section, suggesting retrogression of medium- to high-pressure assemblage. Minor and accessory phases correspond mainly to muscovite, rutile, oxide and zircon. The gneiss consists of alternating quartzofeldspathic layers with a granoblastic texture and biotite $\pm$ sillimanite layers parallel to the foliation, which is also outlined by quartz ribbons (high-temperature mylonitic texture) (Fig. 13d). Garnet contains inclusions of plagioclase, biotite, quartz and rutile, and occurs as mm- to half-cm-sized porphyroblasts commonly surrounded by a quartzofeldspathic aureole confirming the macroscopic observation. It is partly retrogressed into biotite developed in pressure shadows. Plagioclase locally occurs as half-cm size porphyroclasts. Felsic gneiss N14-01c consists mainly of quartz, plagioclase and amphibole. Calc-silicate rocks are mainly comprised of

diopside ($\text{Wo}_{49}\text{En}_{38}\text{Fs}_{13}$; $X_{\text{Mg}} = 0.76 \pm 0.01$), hornblende ($0.65 < X_{\text{Mg}} < 0.75$), calcite, almost totally retrogressed plagioclase, abundant apatite, and titanite. Secondary mineral phases are chlorite ($X_{\text{Mg}} = 0.62$), muscovite and prehnite.

3.3. Migmatitic intermediate to felsic gneisses

One of the main lithological units of the Mbé – Sassa-Mbersi region consists of migmatitic gneisses and heterogeneous granitoids with a composition grading from quartz monzodiorite to leucogranite. They comprise tonalitic gneiss (MM14-05), hornblende ($\pm$ biotite) gneisses (N14-01b, K14-01, NB14-03b, NB14-10a, NB14-07b) and leucogneiss with or without garnet (NB14-03, CK09-1, NFA-02). The heterogeneity of these rocks is also expressed by a variety of textures and an irregular compositional layering at the centimetre to decametre scale (Fig. 8). At one hand of the spectrum, gneisses with an intermediate composition are alternating with migmatitic paragneisses (Fig. 8a) or with amphibolites that are also present as boudins (Figs. 8b, c, d). On the other hand, gneisses with a felsic composition typically display an augen texture suggesting a former magmatic fabric more or less transposed in the main foliation (Fig. 8e, f).

The migmatitic intermediate to felsic gneisses display a dominantly steeply dipping composite foliation S_{n+1} transposing a shallow-dipping foliation $S_{0/n}$. In zones of intense deformation all lithologic contacts are parallel, except for a few coarse-grained mafic boudins and pinched and swelled orthogneissic layers, indicating limited competency contrasts between mafic and felsic layers. Transposed augen gneisses grade into gneisses with feldspar porphyroclasts dispersed into a fine-grained matrix (Fig. 8f). Even in zones of intense deformation, discordant intrusive to partly transposed granitic veins are present (Fig. 8e). In contrast, in these zones, discordant mafic veins are not observed, suggesting that mafic magmatic rocks are pre-tectonic. Based on these features, in zones of penetrative solid-state deformation, it is difficult to determine whether orthogneissic layers correspond to magmatic rocks with a pre-Neoproterozoic protolith, to Neoproterozoic plutonic rocks or even to the leucosome part of Pan-African migmatites.

Under the microscope, a magmatic texture is still perceptible in most gneisses behind the general mylonitic fabric (Fig. 13e). Most gneiss samples consist of porphyroclasts of plagioclase and hornblende ($0.47 \leq X_{\text{Mg}} \leq 0.66$) embedded in a fine- to medium-grained,

heterogeneous matrix consisting of plagioclase and variable amounts of biotite ($X_{Mg} = \sim 0.5$), K-feldspar and quartz. Leucogneiss typically display a high-temperature gneissic fabric outlined by quartz ribbons in a fine-grained granoblastic matrix (Fig. 13f). The matrix contains quartz, K-feldspar and plagioclase, with minor biotite ($0.55 \leq X_{Mg} \leq 0.59$) or garnet ($Alm_{57-69}Prp_{24-30}Sps_{\leq 3}Grs_{4-15}$). The composition of plagioclase ranges from An_{40} in hornblende ($\pm$ biotite) gneiss samples to An_{20-25} in the most silicic ones. Accessories in all these rocks consist of zircon, apatite and oxides, whereas secondary phases are chlorite, prehnite and muscovite.

3.4. Plutonic rocks

In the Mbé – Sassa-Mbersi area, plutonic rocks include mafic to intermediate microgranular enclaves (samples SM13-3b, SM13-1a, NB14-12, SM13-3c), tonalite and trondhjemite (L14-03, NG14-02, NB14-08a), hornblende-biotite granite (CK13-6c, NB14-20, M13-1c, NB14-04), biotite granite (M13-3c, L14-01, NB14-40, MM14-07) and leucogranite. Decimetre to meter-sized microgranular enclaves are common in granitic rocks, showing sub-rounded or elongated shapes. The main mineral phase assemblage of the studied samples consists essentially of plagioclase (An_{24-31} ; 15–30 vol.%), amphibole (magnesio-hornblende and tschermakite; 30–47 vol.%), biotite, K-feldspar and quartz. Accessory phases are titanite, apatite, zircon and opaque minerals. Secondary phases consist of chlorite, epidote, prehnite and calcite replacing biotite and amphiboles; and of sericite grown at the expense of feldspars.

Tonalite occurring in the northern part of the study area, corresponds to light pink, medium-grained rocks. It consists of quartz, plagioclase (An_{27-29}), minor K-feldspar, biotite, amphibole (magnesio-hornblende and tschermakite); accessories are titanite, Fe-Ti oxide, zircon. Tonalite is deformed showing alternating mesocratic and leucocratic fine banding and mineral preferred orientation. Trondhjemite occurs at the Mbaou and Ndong Benue localities as veins or dykes of variable thickness. The main mineral phases are zoned plagioclase (An_{27-29}), quartz, and minor K-feldspar and biotite; accessory minerals are oxide and zircon. Secondary minerals are sericite and chlorite, resulting from the transformation of feldspar and biotite, respectively. Tonalite and trondhjemite show submagmatic to subsolidus deformation, with quartz-filled fractures in feldspars, mechanical twinning in plagioclase, kink-band in biotite and sub-grain development along quartz–quartz boundaries.

Hornblende-biotite granites are medium- to coarse-grained (0.2–3 mm), equigranular to heterogranular rocks. They are compositionally heterogeneous due to mingling between mesocratic monzodioritic and leucocratic granitic facies. Hornblende-biotite granites consist of quartz (20–25 vol.%), plagioclase (An_{24–29}; 30–35%), more or less perthitic K-feldspar (Or_{87–97}), biotite (~10%), amphibole (magnesio-hornblende and ferro-tschermakite; ~10%). Accessories consist of Fe-Ti oxide commonly rimmed with titanite, zircon, apatite and secondary chlorite. They also individually outcrop in the Mbaou and Home localities at the East of study area (Fig. 3). Minerals are stretched according to the regional foliation including σ and δ plagioclase porphyroclasts that are generally recrystallized in small polygonal neoblasts.

Biotite granites are the most abundant plutonic rock of the Mbé – Sassa-Mbersi area, occurring as veins or plutons mostly in the southern part of the area. They are coarse- to fine-grained, greyish to pinkish rocks (Fig. 9). They consist of quartz, plagioclase (An_{10–30}), K-feldspar and variable amount of biotite and accessory minerals (oxide, titanite, apatite, epidote and zircon). Textures range from magmatic heterogranular to mylonitic locally. A mineral preferred orientation is commonly observed, locally outlined by phenocrysts of perthitic K-feldspar. Leucogranites occur as sheeted dykes, locally boudinaged in the foliation plane. In this case, porphyroclasts of feldspar are moulded in a fine-grained matrix, with quartz ribbons showing evidence of dynamic recrystallization.

3.5. Mylonites and shear zones

All lithologic units described above are affected by solid-state ductile deformation with a variable intensity. Strain gradients are expressed by transposition of lithologic contacts and by reduction of the grain size associated with mylonites and ultramylonites delineating shear zones.

The main shear zone of the studied area is the NE–SW trending Tcholliré-Banyo Shear Zone following the Benue river bed and crossing the towns and villages of Mbé, Karna and Ndom (Figs. 10 and 11). As described above, the Tcholliré-Banyo Shear Zone is associated with the presence of elongated plutonic bodies that are partly to totally transposed in accordance with the mylonitic fabric, consistent with a pre- to syn-tectonic emplacement of these plutons. In the Karna quarry, mylonites are preferentially developed to the expense of metabasic rocks

while near Ndom, the mylonite contains numerous σ and δ shaped feldspar porphyroclasts pointing to a granitic protolith. However, the intensity of deformation precludes the identification of the protoliths of these mylonitic rocks solely on petrological criteria. Orthogneissic layers could represent deformed equivalent of the intermediate to felsic gneisses and/or transposed plutonic rocks of the Tcholliré-Banyo batholith. The foliation of metabasites and orthogneisses, locally marked by thin leucosome concordant veins, delineates sheath folds with axes parallel to the stretching and mineral lineation. This foliation is grading into mylonite to ultramylonite associated with an extreme reduction of the grain size resulting in a dark matrix enclosing dispersed rounded porphyroclasts. The attitude of the mylonitic fabric varies at outcrop scale with NE–SW trending subvertical planes associated with a shallow-dipping lineation next to planes with a shallow-dip to the N also carrying a NE–SW trending lineation. The subvertical mylonitic fabric is characterized by kinematic criteria (sigma porphyroclasts and cross-cutting shear planes) consistent with a sinistral sense of shear. The shallow-dipping mylonitic fabric is associated with C' shear bands and delta porphyroclasts consistent with a top to the WSW sense of shear. The subvertical and shallow-dipping mylonitic shear zones display mutual cross-cutting relationships and are expressed by similar mineral assemblages including the presence of amphibole or biotite.

The NE–SW S_{n+1} foliation is cross-cut but by E–W trending subvertical shear zones that also offset the Tcholliré-Banyo Shear Zone (Fig. 12). The strain gradient associated with these shear zones is much sharper than the one related to the sinistral NE–SW trending shear zones. The mylonitic fabric is also marked by retrogression of amphibole and biotite in chlorite and epidote. Accordingly, these E–W trending shear zones postdate the main HT fabric of the rocks of the Mbé – Sassa-Mbersi region. It is to note that the E–W shear zones contains boudins of granitic veins but are also cross-cut by granitic dykes with a magmatic fabric or partially transposed.

These features indicate that deformation recorded by high-grade rocks of the Mbé – Sassa-Mbersi region occurred in the presence of melt during the development of S_{n+1} . Melt segregation and magma migration is also expressed by emplacement of plutons into sinistral shear zones, in particular into the Tcholliré-Banyo Shear Zone, and eventually into dextral shear zones for the last granitic magmas.

4. Major and trace element geochemistry

Whole-rock major and trace elements compositions were determined in 33 samples of metamorphic rocks and 15 samples of plutonic rocks at the Service d'Analyse des Roches et Minéraux (SARM, CRPG-CNRS, Nancy) following the procedure described in Carignan et al. (2001). Typical analytical precisions are ca. 2% for major elements and 5–8% for trace elements. Analytical data are given in Tables 1 to 4, and sample location in the Supplementary material (Table SMI).

4.1. Metabasic rocks

The metabasic rocks showing compositions ranging from gabbro to diorite (Table 1 and Fig. 14), are subdivided in two groups on the basis of their major elements characteristics (Fig. 15a, b). The more magnesian group, corresponding to mafic cumulates, comprises hornblendite (NB14-05, NB14-44 and ML14-08), metagabbro (NB14-07a and NB14-11c) and type 1 amphibolite (NB14-11d, NB14-11b, ML14-01a and ML14-04). This group is characterized by high concentrations in $\text{Fe}_2\text{O}_3^{\text{tot}}$ (10.0–14.6 wt.%), MgO (8.4–17.8 wt.%; $\text{Mg\#} = 54\text{--}77$) and CaO (9.6–12.8 wt.%; $\text{CaO/SiO}_2 > 0.24$). With the exception of one sample (ML14-01a: $[\text{La/Yb}]_{\text{N}} = 47.9$; $[\text{Gd/Yb}]_{\text{N}} = 7.0$), the REE patterns (Fig. 16a) are moderately fractionated ($[\text{La/Yb}]_{\text{N}} = 1.9\text{--}7.4$; $[\text{Gd/Yb}]_{\text{N}} = 1.3\text{--}2.6$), with typical concave downward light REE. Trace element compositions show variable but rather high concentrations in Cr (104–1457 ppm), Ni (30–341 ppm), Sc (33–56 ppm) and V (178–366 ppm). Multi-element plot shows negative anomalies in Th, U, Ta, Nb, P, Zr, Hf and Ti (Fig. 16b). Th/Yb vs. Nb/Yb plot (Fig. 15d) show that some of these rocks spread along the mantle array, while others are shifted towards the field of magma contaminated by crustal material.

The other group is made of amphibolite samples with higher and more variable $\text{Fe}_2\text{O}_3^{\text{tot}}$ contents (8.4–16.8 wt.%) and significantly lower concentrations in MgO (3.5–7.7 wt.%; $\text{Mg\#} = 32\text{--}49$) and CaO (5.4–9.6 wt.%; $\text{CaO/SiO}_2 < 0.24$), (Fig. 15a, b) compared to the mafic cumulates. They have the composition of basalts and basaltic andesites, with silica contents ranging from 45.2 to 53.9 wt.% and FeO^*/MgO ratios indicative of a tholeiitic chemistry (Fig. 15c). This group comprises two types of amphibolites, designated as type 2 and type 3, distinguished on the basis of their REE concentrations. Type 2 amphibolites (samples NB14-08c, NB14-08b and NB14-10) show weakly fractionated patterns ($[\text{La/Yb}]_{\text{N}} = 2.6\text{--}2.8$; $[\text{Gd/Yb}]_{\text{N}} = 1.4\text{--}1.6$) and almost no Eu anomaly ($\text{Eu/Eu}^* = 0.9\text{--}1.1$) (Fig. 16c). These samples

show lower Ba (38–280 ppm), Rb (6–18 ppm) and Sr (140–290 ppm) contents compared to the other amphibolite samples. They have rather high TiO₂ and V contents (1.7–2.5 wt.%, 302–311 ppm, respectively), with Ti/V ratios (34–42) within the range of Mid Ocean Ridge Basalts (MORB) (Shervais, 1982). They are also characterized by Th/Yb and Nb/Yb ratios close to E-MORB (Fig. 15d). Multi-element plot (Fig. 16d) shows weakly fractionated patterns, with very slight positive Ti anomaly and negative anomalies in P and Sr. Type 3 amphibolites (samples NB14-11a, NB14-11e, N14-01a-2 and N14-01a-1) show low Nb/La ratios (0.13–0.21) compared to other types, and strongly fractionated REE patterns (Fig. 16e), with [La/Yb]_N = 9.6–21.9, [Gd/Yb]_N = 2.6–3.4) and almost no Eu anomaly (Eu/Eu* = ~0.9). Their TiO₂ and V contents (1.3–1.7 wt.%; 144–212 ppm, respectively) are lower than in the former type, but the Ti/V ratios are higher (41–61). Their Th/Yb and Nb/Yb ratios are variable, with Th/Yb values extending from the asthenospheric mantle array close to E-MORB to high values laying within the field of subducted sediments (Fig. 15d). Multi-element plot (Fig. 16f) shows pronounced negative anomalies in Th, U, Ta, Nb, P, Zr, Hf and Ti. These data suggest that the magmatic protolith of some type 3 amphibolites and cumulates rocks could possibly derive from partial melting of a mantle contaminated by sediments potentially recycled along a subduction zone.

4.2. Paragneisses and calc-silicate gneiss

Whole-rock major element composition of paragneisses (Table 2) spreads over the fields of greywackes (felsic gneiss N14-01c, garnet gneisses NB14-26ab, MM14-01, NB14-01a and NB14-02) and shales (fine-grained garnet gneiss NB14-01b) in the Fe₂O₃^{tot} + CaO + TiO₂ vs. Al₂O₃ diagram (Fig. 14). Garnet gneiss and felsic gneiss samples show silica content ranging from 62.6 to 71.7 wt.%, significant amounts of CaO (1.6–3.2 wt.%), variable Na₂O (1.9–4.5 wt.%) and rather low K₂O (1.5–2.2 wt.%). Rather high Zr content (183–695 ppm) suggests the presence of a significant zircon component in the sedimentary protolith. Sr is variable but remains in a limited range (205–406 ppm). Cr and Ni concentrations are variable, and rather high in some samples (120–498 and 61–270 ppm, respectively). Sample N14-01c shows very high concentrations in Cr and Ni for a silicic rock; however, the fairly normal Cr and Ni contents in other rock samples and in Nb in this sample lead us to exclude contamination during sample preparation. A control by ore minerals cannot be excluded. Rare-earth element (REE) patterns (Fig. 17a) are moderately fractionated ([La/Yb]_N = 4.4–15.4), with weakly fractionated heavy REE ([Gd/Yb]_N = 1.2–2.7) and weak negative Eu anomalies (Eu/Eu* =

~0.8). Multi-element plot normalized to primitive mantle shows negative anomalies in U, Ta, Nb, Sr, P and Ti (Fig. 17b). These data and comparison with various average whole-rock compositions (Fig. 17a) suggest an immature siliciclastic sedimentary protolith, possibly involving reworking of mafic rocks if we consider the rather high Cr and Ni content of some samples. The fine-grained garnet gneiss sample (NB14-01b) is distinguishable by lower SiO₂ (~53 wt.%) and higher Al₂O₃ (21.6 wt.%), CaO (5.3 wt.%), Na₂O (4.5 wt.%) and K₂O (3.35 wt.%); however, in spite of a high alumina content, it does not show the typical composition of shale as shown by the high concentrations in CaO and Na₂O, as well as in Sr (1348 ppm) and Ba (~2500 ppm). This is also supported by highly fractionated REE pattern clearly distinct from average shale (Fig. 17a), with [La/Yb]_N = 23.4, [Gd/Yb]_N = 6.7, low heavy REE content (Yb_N = 5.5) and no Eu anomaly (Eu/Eu* = ~1.0). The multi-element plot (Fig. 17b) shows negative anomalies in Th, U, Ta and Nb. These features resemble those of intermediate igneous rocks and suggest the involvement of volcanic or plutonic material in the source of the sedimentary protolith of these gneisses.

Whole-rock major element composition of calc-silicate rocks is distinguishable by low silica content (41.3 and 46.2 wt.%) together with high concentrations in CaO (16.3 and 19.8 %), P₂O₅ (1.3 and 4.1 %), Fe₂O₃^{tot} (8.7 and 9.3 %) and MgO (7.9 and 8.2 %). Concentrations in alumina (8.13 and 16.07 %) and alkalis are variable (Table 2). The REE concentrations are high, with light REE reaching 1000 times chondrite in one sample, and the patterns (Fig. 17a) are fractionated ([La/Yb]_N = 22.8 and 38.2; [Gd/Yb]_N = 7.2 and 7.5), with a weak negative anomaly in Eu (Eu/Eu* = 0.8) for the sample with the lowest Al₂O₃ content. The multi-element plot (Fig. 17b) shows negative anomalies in K, Nb, Ta, Zr, Hf and Ti. Amongst the other trace elements, one should note the high concentrations in Sr (895 and 1672 ppm), Cr (240 and 817 ppm) and Ni (153 and 483 ppm). This peculiar composition characterized by high contents of both Fe and Mg, together with high Ca, Sr, P, REE, Cr and Ni led us to consider that these calc-silicate rocks are not simple mixture between siliciclastic detrital material and carbonate precipitates (dolomite, calcite or siderite), but could rather involve (hydrothermal?) alteration of mafic volcanogenic material accompanied with carbonate and phosphate precipitation.

4.3. Migmatitic intermediate to felsic gneisses

The heterogeneity of migmatitic intermediate to felsic gneisses presented in the petrography section is illustrated in the $\text{Fe}_2\text{O}_3 + \text{CaO} + \text{TiO}_2 - \text{Al}_2\text{O}_3$ diagram (Fig. 14), with compositions ranging from monzodiorite to granite (Table 3). Samples with a quartz monzodioritic composition (N14-01b, K14-01, NB14-03b and MM14-05) show silica content around 57–59 wt.%, rather high FeO and MgO contents (5.8–8.3 and 3.0–4.6 wt.%, respectively) and variable CaO content (5.6–11.5 wt.%). They are metaluminous ($0.54 \leq A/\text{CNK} \leq 0.92$), magnesian and calc-alkaline in the classification of Frost et al. (2001). Sample NB14-10a has a composition of quartz monzonite ($A/\text{CNK} \leq 1.03$; $\text{SiO}_2 = 62.4$ wt.%, $\text{K}_2\text{O}/\text{Na}_2\text{O} = 0.94$), while sample NB14-07b is tonalitic, ($A/\text{CNK} \leq 0.96$; $\text{SiO}_2 = 67.5$ wt.%, $\text{K}_2\text{O}/\text{Na}_2\text{O} = 0.33$). The most silicic samples (NB14-03b, CK09-01 and NFA2) are slightly peraluminous ($1.01 \leq A/\text{CNK} \leq 1.05$), ferroan and calcic, with monzogranitic (NB14-03) or syenogranitic (CK09-01 and NFA2) compositions.

The REE patterns (Fig. 17c) of the samples with a monzodioritic composition (K14-01, NB14-03b and MM14-05) show moderately fractionated REE ($[\text{La}/\text{Yb}]_N = 6.2\text{--}10.7$; $[\text{Gd}/\text{Yb}]_N = 1.5\text{--}2.1$), high chondrite-normalized Yb content ($\text{Yb}_N > 10$) and negative Eu anomaly ($\text{Eu}/\text{Eu}^* = 0.7\text{--}0.9$). Samples N14-01b, NB14-07b and NB14-10a are distinguishable by more fractionated REE ($[\text{La}/\text{Yb}]_N = 18.6\text{--}30.4$) and lower Yb contents ($\text{Yb}_N = 3.2\text{--}7.4$), associated to high Sr/Y ratio (45.1–93.8) compared to the other samples ($\text{Sr}/\text{Y} \leq 37$). Sample NB14-03 shows fractionated REE pattern with $[\text{La}/\text{Yb}]_N = 9.7$, $[\text{Gd}/\text{Yb}]_N = 1.4$ and a slight negative Eu anomaly ($\text{Eu}/\text{Eu}^* = 0.9$). The variability of the heavy REE content and Sr/Y ratio suggest heterogeneity in the source of these migmatitic gneisses. The two most silicic samples show distinct REE patterns, with an important negative Eu anomaly for sample NFA2 ($\text{Eu}/\text{Eu}^* = 0.2$), and a $[\text{La}/\text{Yb}]_N$ ratio of 0.5 for sample CK09-01. Multi-element plot (Fig. 17d) shows systematic negative anomalies in Nb, Ta and P; and negative anomalies in Th, U and Ti in most samples.

4.4. Plutonic rocks

Plutonic rock samples cover a wide range of composition from the field of monzogabbro (microgranular enclaves) to the field of syenogranite in the normative Q'–ANOR diagram (Fig. 18a and Table 4). Samples are dominantly metaluminous, high-K alkali-calcic and magnesian, with the exception of the tonalitic and trondhjemitic samples (L14-03, NG14-02 and NB14-08a), which are low-K calc-alkaline, and of the biotite granite samples (M13-3c,

L14-01, NB14-40 and MM14-07), which are slightly ferroan and localized in the shoshonitic field (Fig. 18b–d). Overall, these samples show I-type geochemistry, consistent with the mineralogical composition characterized by the presence of amphibole and biotite as the only mafic silicate minerals. Rb and Y+Nb contents (Fig. 18e) mostly overlap the field of post-collisional granites, with the exception of two tonalitic and one monzodioritic samples shifted towards the volcanic arc field. Multi-element plots (Fig. 19b, d, f, h) show systematic negative anomalies in Ta, Nb, P and Ti.

Microgranular enclaves are of two types. Three samples (SM13-3b, SM13-1a, NB14-12) correspond to mafic enclaves with SiO₂ ranging from 49.1 to 54.2 wt.%; they also have high Fe₂O₃^{tot} (7.6–11.1 wt.%) and CaO (5.6–8.9 wt.%) contents. The fourth sample (SM13-3c) shows a monzogranitic composition (Fe₂O₃^{tot} = 4.3, MgO = 1.6, CaO = 3.1 wt.%). Concentrations in Ba (1276–2520 ppm), Sr (696–1541 ppm) and Zr (75–386 ppm) are high and suggest contamination by the granitic host-rock. The REE patterns (Fig. 19a) are fractionated ([La/Yb]_N = 8.4–25.9, Gd/Yb]_N = 2.1–2.8), with weak but variable Eu anomalies (Eu/Eu* = 0.9–1.1) and high heavy REE content (8.5 ≤ Yb_N ≤ 20.4).

The quartz-monzodioritic to granitic samples show SiO₂ and Fe₂O₃^{tot} contents ranging from 56.7 to 65.8 wt.% and 7.2 to 4.8 wt.% in hornblende-biotite granitoids, and from 68.8 to 72.4 and 3.5 to 1.8 % in biotite granite. The tonalitic (L14-03, NG14-02) and trondhjemitic (NB14-08a) samples differ by more variable SiO₂ (60.7–74.1 wt.%) and Fe₂O₃^{tot} (7.4–1.5 wt.%) contents and lower K₂O/Na₂O ratios (~0.4 compared to 0.57–3.3 in other granite types). Their REE patterns (Fig. 19e) are moderately fractionated ([La/Yb]_N = 8.7–14.6, Gd/Yb]_N = 2.0–2.2), with positive Eu anomaly (Eu/Eu* = 1.1/1.6) and low Yb content (Yb_N ≤ 4.7), with the exception of the more mafic sample (L14-03) showing negative Eu anomaly and higher Yb_N (11.2). Hornblende-biotite granite show moderately fractionated REE patterns ([La/Yb]_N = 7.0–24.9, [Gd/Yb]_N = 1.3–3.0), with negative Eu anomaly (Eu/Eu* = 0.7–0.9) and Yb_N content ranging from 6.7 to 19.3 (Fig. 19c). The REE patterns of the biotite granite samples (Fig. 19g) are strongly fractionated ([La/Yb]_N = 41.7–99.8, Gd/Yb]_N = 3.4–7.1), with enrichment in light REE (La_N = 256–792), a significant negative Eu anomaly (Eu/Eu* ≤ 0.5) and low Yb content (Yb_N = 5.6–8.3). Multi-element plot show a significant enrichment in large ion lithophile elements (Fig. 19h).

Overall, major and trace element data show that the plutonic rocks sampled in the Mbé – Sassa-Mbersi region correspond to three magmatic series: medium-K, high-K and shoshonitic. The magnesian medium-K series corresponds to the tonalitic and trondhjemitic samples characterized by fractionated REE patterns with low heavy REE concentrations, suggesting a possible origin by partial melting of mafic material involving fractionation of amphibole and garnet. The high-K series is represented by the hornblende-biotite granite samples and some mafic to intermediate microgranular enclaves; they show fractionated REE patterns but the concentration in heavy REE, around 10 times chondrite, is higher than in the tonalitic series, therefore suggesting generation of parent magmas with less garnet in the residue. The shoshonitic series corresponds to the biotite granites characterized by very high light REE contents. Nevertheless, in the absence of isotopic data it is not possible to go farther into the interpretation of the source of these rocks.

5. Metamorphic petrology and P – T conditions

Pressure-temperature conditions of metamorphism have been estimated using both phase equilibria modelling and conventional thermobarometry. In order to constrain these P – T conditions, we have selected one garnet paragneiss (NB14-01a) sampled along the Benue River for which we have computed pseudosections using Perple_X 6.7.9 (Connolly, 2005) and the updated 2011 version of the internally-consistent thermodynamic database of Holland and Powell (2011). The studied sample corresponds to a metatexite, with leucosomes forming thin bands conformable to the foliation, or occurring as leucocratic aureole around garnet porphyroblasts. The migmatitic foliation (S_{n+1}) is underlined by the biotite + sillimanite association (Fig. 13d). The main mineral phases consist of quartz, plagioclase, limited amount of K-feldspar, garnet, biotite, sillimanite, rutile and Fe-Ti oxide. Garnets are composed of a poikiloblastic core surrounded by an almost inclusion-free rim seemingly in equilibrium with sillimanite.

Pseudosection of Fig. 20 was calculated in the TiO_2 – Na_2O – CaO – K_2O – FeO – MgO – Al_2O_3 – SiO_2 – H_2O (TNCKFMASH) system. Phases involved in modelling are Biotite (Bt), K-feldspar (Fsp), Garnet (Gt), Kyanite (Ky), Melt (L), Plagioclase (Pl), Quartz (Qtz), Rutile (Rt), White Mica (Ms), Sillimanite (Sil), Ilmenite (Ilm) and Staurolite (St). The solution models utilized for metamorphic minerals and the bulk rock composition are presented in the Supplementary material (Tables SM2 and SM3, respectively). The amount of H_2O in the pseudosection

calculations is a critical variable that cannot be inferred solely on the basis of bulk composition analyses (i.e. loss-on-ignition). The amount of water involved at high temperature is determined via a series of T - M_{H_2O} pseudosections, such that the solidus is water-saturated at 1.0 GPa. To refine the P - T conditions experienced by the garnet paragneiss, the phase diagram section has been contoured for X_{Mg} , X_{Ca} and X_{Fe} in garnet. The grossularite content ($0.12 \leq X_{Ca} \leq 0.15$) is the component that will be the least modified by retrograde exchange reactions (Pattison and Bégin, 1994); and when in equilibrium with biotite and melt, it is a good geobarometer. P - T estimates on this migmatitic garnet paragneiss (Fig. 20) show that pressure peak (M_1) recorded by the grossularite content in garnet cores range in pressure from 1.22 to 1.36 GPa and in temperature from 765 and 775°C. The high temperatures given by modelling are consistent with the high TiO_2 content of biotite (4.9–5.6 wt.%; Table SM3). The metamorphic peak is followed by an adiabatic decompression down to 0.72–0.86 GPa and 760–780°C recorded by the grossularite-poor garnet rims ($0.04 \leq X_{Ca} \leq 0.05$).

Conventional thermometry has been applied to garnet amphibolite using the garnet-hornblende thermometer calibrated by Ravna (2000). Calculation applied to 10 garnet-hornblende pairs (sample ML14-01b; Table SM3) yield peak temperatures in the range of 720–870°C (average: $793 \pm 51^\circ\text{C}$), with no systematic difference by applying core and rim analyses. Although in agreement with the temperatures obtained from the *Perple_X* pseudosection, the large range of temperature obtained on garnet amphibolites could in fact indicate disequilibrium between phases.

6. LA-ICP-MS zircon U-Pb data

In order to determine the timing of the Pan-African metamorphic event and emplacement age of some of the plutonic rocks, we have separated zircon grains from garnet gneiss (NB14-02) and amphibolite (NB14-11a and NB14-11b), tonalite, hornblende-biotite granite and pegmatitic granite. The distinction of metamorphic and magmatic zircon is based on textural and geochemical characteristics including the Th/U ratio, which has shown to be efficient in most cases (Corfu et al., 2003; Martin et al., 2008; Rubatto, 2002; Williams and Claesson, 1987; Zeh et al., 2010) despite some limitations (Harley et al., 2007; Möller et al., 2003).

6.1. Analytical techniques

Rock samples were crushed, sieved and washed at Géosciences Environnement Toulouse (GET) laboratory (France). The 50 μm to 500 μm fraction was then concentrated using heavy liquids (bromoform and diiodomethane) and magnetic separation with a Frantz isodynamic separator. Zircon grains were subsequently hand-picked under a binocular microscope, mounted in epoxy blocks, and polished to expose their centre parts. Internal textures and zoning were imaged using combined secondary electron microscopy (SEM), cathodoluminescence (CL) and back-scattered electron (BSE) imaging techniques, obtained with a JEOL JSM-6490 instrument coupled with a Gatan MiniCL at the Goethe – Universität Frankfurt am Main (Germany). U-Pb isotopes analyses of zircon grains were carried out successively by laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS), using a Thermo-Finnigan ELEMENT and NEPTUNE mass spectrometer coupled to an RESONETIC 193nm Excimer laser, at the Goethe – Universität Frankfurt am Main, Campus Riedberg (Germany). Methods and instruments were the same as described in detail by Gerdes and Zeh (2006, 2009), with modifications explained in Zeh and Gerdes (2012). LA-ICP-MS methodology, analytical data and cathodoluminescence images of selected zircon grains are given in Supplementary material (Table SM4, Table SM5 and Plate SM6, respectively).

6.2. Zircon U–Pb data

Garnet paragneiss (sample NB14-02). Zircon grains mostly present a sub-rounded to rounded shape and range in size from 50 to 200 μm . SEM/CL images reveal zircon grains with complex internal structure with oscillatory zoning partially obliterated by re-crystallization. Some grains show core-rim relationships, with xenocrystic magmatic cores, surrounded by CL-dark metamorphic rims. Some grains with a sub-euhedral shape are devoid of inherited cores and display oscillatory zoning. A total of 43 U–Pb analyses were acquired. The results are shown in the Concordia diagram in Fig. 21a–b, and in the population density diagram in Fig. 21c. In the population density diagram all data >1000 Ma represent $^{207}\text{Pb}/^{206}\text{Pb}$ ages, and those <1000 Ma $^{206}\text{Pb}/^{238}\text{U}$ ages. The magmatic zircon grains/domains, all of them characterized by oscillatory zoning and relatively high Th/U ratios (mostly >0.2), reveal three groups of dates. Four grains give Neoproterozoic $^{207}\text{Pb}/^{206}\text{Pb}$ dates between 2750 and 2500 Ma (all highly discordant), five grains give Paleoproterozoic $^{207}\text{Pb}/^{206}\text{Pb}$ dates between 2040 and 1800 Ma (one at 2040 Ma is nearly concordant), and 34 grains give Neoproterozoic dates. The

youngest of the Neoproterozoic magmatic grains yields a $^{206}\text{Pb}/^{238}\text{U}$ date of 725 ± 12 Ma (concordance $\geq 95\%$), which is tentatively interpreted as the maximum depositional age. The diversity of ages obtained on inherited zircon grains is consistent with a sedimentary origin for the investigated migmatitic garnet gneiss. Metamorphic zircon rims, characterized by low Th/U ratios and diffuse, CL-dark zoning, yield concordant dates between ca. 640 and 565 Ma. Three of these rims, characterized by variable Th/U ratios between 0.25 and 0.01, give a Concordia date of 620 ± 14 Ma (MSWD = 1.8; $n = 3$), and five rims, all with very low Th/U ratios < 0.10 , a Concordia date of 582 ± 4 Ma (MSWD = 0.87; $n = 6$). The older age might date an early metamorphic stage or, alternatively, results from the incomplete recrystallization of inherited magmatic grains during the Pan-African high-grade metamorphic overprint, which most likely occurred at 582 ± 4 Ma.

Amphibolite (samples NB14-11a and NB14-11b). Zircon grains are typically sub-euhedral to anhedral (zircon fragment), with size ranging from 200 to 450 μm and show an oscillatory zoning or sector zoning, typical for magmatic zircon. Some grains display a narrow irregular metamorphic rim around the magmatic core. Th/U ratios range from 0.3 to 2.2 for sample NB14-11a and from 0.8 to 2.4 for sample NB14-11b. A total of 40 U–Pb analyses were acquired. Both samples gave within error identical concordant dates of 600 ± 4 Ma for sample NB14-11a (MSWD=0.60; $n = 7$; Fig. 21d) and 599 ± 6 Ma for sample NB14-11b (MSWD=0.58; $n = 5$; Fig. 21e). These ages are interpreted to represent the time of crystallization of the mafic magmas during the Pan-African orogeny.

Tonalite (sample NG14-02). Zircon grains in the tonalite NG14-02 show euhedral to sub-euhedral shapes. They are stubby or long prismatic, with length ranging from 200 to 500 μm . Cathodoluminescence images show an oscillatory zoning suggesting a magmatic origin. A total of 20 zircon domains were analyzed. All analyses domains reveal Th/U ratios between 0.49 and 0.99, which are typical of magmatic zircon. Twelve analyses yield a Concordia date of 651 ± 3 Ma (MSWD=0.99; $n = 12$; Fig. 21f), which is interpreted to reflect the time of crystallization of the tonalitic magma.

Hornblende-biotite granite (sample M13-01D). Zircon grains are prismatic, euhedral to subhedral, oscillatory zoned, with length ranging from 100 to 450 μm . A total of 39 U–Pb spot analyses were obtained on 30 grains. The analysed domains show Th/U ratios of 0.43–2.29, and gave a concordant date of 599 ± 2 Ma (MSWD = 2.0; $n = 20$; Fig. 21g), which

overlaps within error with an upper intercept age of 605 ± 7 Ma comprising all 39 analyses. Concordia age is interpreted to reflect the time of magma crystallization.

Pegmatite granite (sample NB14-09). Zircon grains are subhedral, oscillatory zoned, but their cores are locally blurred by patchy zoning. Ten U–Pb analyses made on 5 grains show Th/U ratios varying from 0.12 to 0.90. They give a concordant date of 573 ± 3 Ma (MSWD = 0.097; $n = 7$; Fig. 21h) within error identical to the upper intercept age of 572 ± 10 Ma. This age is interpreted as the crystallization time of the pegmatite.

7. Discussion

7.1. Nature and ages of the protoliths of metamorphic rocks

All authors agree that the Central Cameroon domain is dominantly derived from Archean to Paleoproterozoic material with a limited volume of juvenile magmatic addition during the Neoproterozoic and intense reworking during the Pan-African orogeny (Ngako et al., 2003; Toteu et al., 2004; 2006a, 2006b; Kwekam et al., 2010; Ngako and Njonfang, 2011; Bouyo et al., 2013; 2015; Tchakounté et al., 2017). However, propositions differ on the nature of the protoliths that have been affected by deformation and metamorphism and on the nature and sources of the juvenile magmas. Kwekam et al. (2010) propose that the migmatitic gneisses correspond to Archean-Paleoproterozoic basement reworked (metacratonized) during the Pan-African as a result of subcontinental lithospheric mantle zonal delamination following collision between the Sahara and Congo cratons. Corroborating this model, Tchakounté et al. (2017) have argued that this basement comprises Archean tonalites reworked during a high-grade Paleoproterozoic metamorphic event. The model of Toteu et al. (2004) introduces a nuance regarding the nature of the basement, proposing a Paleoproterozoic age but with an origin dominated by sediments initially derived from erosion of the Archean Congo Craton deformed and metamorphosed during the Eburnean orogeny.

The data of this study document the presence in the Central Cameroon domain of paragneisses and of amphibolites with Neoproterozoic protoliths ages. Indeed, U–Pb ages obtained on detrital zircon cores from garnet paragneiss (NB14-02), derived mostly from magmatic grains, point to the contribution of Archean (ca. 2.75–2.5 Ga), Paleoproterozoic (ca. 2.04–1.8 Ga), and Neoproterozoic sources (ca. 800–725 Ma). The U–Pb date of the youngest

magmatic zircon grain found in the garnet paragneiss (NB14-02) constrains deposition $<725 \pm 12$ Ma. Overall, the metasediments sampled along the Benue River have a chemical composition indicating a dominant felsic source implying the proximity of a continental crust. Alternations of medium-grained gneiss and fine-grained gneiss are considered to correspond to inherited sedimentary compositional layering while leucosome/mesosome alternations reflect melt/crystal segregation. These metasediments might be equivalent to the ones exposed in the Poli and Lom series, respectively located north of the Banyo-Tcholliré Shear Zone (Bouyo et al., 2015) and in the southern part of the Central Cameroon Domain (Ngako et al., 2003; Toteu et al., 2006b). The metamorphic rocks include also at least some amphibolites (NB14-11a and NB14-11b) with U-Pb dates on zircon of ca. 600 Ma that point to the emplacement of mafic magmas during the Pan-African orogeny.

The protolith of the migmatitic intermediate to felsic gneisses is more difficult to assess owing to the intensity of Pan-African deformation and metamorphism. As stated above, previous workers suggested that these gneisses represent relics of a reworked Archean-Paleoproterozoic basement (Toteu et al., 2004; Ngako et al., 2006; Ngako and Njonfang, 2011; Tchakounté et al., 2017). Alternatively, the composition and texture of the migmatitic intermediate to felsic gneisses could be related to intense partial melting of metabasic and metasedimentary-metavolcanic rocks beyond the metatexite-diatexite transition allowing for efficient magma mobility. This proposition is consistent with the locally preserved intrusive contacts of the migmatitic intermediate to felsic gneisses into the metabasic and metasedimentary-metavolcanic rocks. Nevertheless, this does not preclude the presence of pre-Neoproterozoic rocks that could have participated in the generation of the migmatites.

7.2. Petrogenesis of magmatic rocks

The Mbé – Sassa-Mbersi region is characterized by a variety of Neoproterozoic plutonic rocks that have an I-type geochemistry but spread from magnesian medium-K calc-alkaline (tonalites and trondhjemites) and high-K calc-alkaline (hornblende-biotite granites), to ferroan shoshonitic (biotite granites). This geochemical trend also corresponds to a chronologic trend with U-Pb zircon ages of 651 ± 3 Ma (tonalite NG14-02), 599 ± 2 Ma (hornblende-biotite granite M13-01D), and 573 ± 2 Ma (pegmatite NB14-09). These emplacement ages fall in the range of previously published ages for plutonic rocks emplaced along the Tcholliré-Banyo shear zone, namely 686 ± 17 and 640 ± 15 (NW of Bangwa; Tchankam et al., 1997), 638 ± 2

Ma at Bangwa (Njiekak et al., 2008), 632 ± 5 Ma at Tonga (Njiosseu et al., 2005a, b; Toteu and Penaye, 2005), 642 ± 2 , 628 ± 3 and 613 ± 6 Ma at Bafia (Tchakounté et al., 2017), and 576 ± 4 Ma at Kekem (Kwékam et al., 2013).

In the tectonic discrimination diagram of Pearce et al. (1984), plutonic rocks of the Mbé – Sassa-Mbersi region spread from the volcanic arc field for tonalites-trondhjemites to the field of post-collisional granites (hornblende-biotite granites and biotite granites; Fig. 18e). Plutonic rocks are all marked by LILE enrichment and negative Nb, Ta, P and Ti anomalies that tend to increase from the monzodioritic to the monzogranitic pole. The very low HREE content and the marked negative Nb-Ta anomaly of tonalites-trondhjemites of the magnesian medium-K series could reflect an origin by partial melting of a subducted slab in presence of variable amount of garnet. The signature of the hornblende-biotite and biotite granites is not strongly discriminative but the higher concentration in heavy REE relative to the magnesian medium-K series is consistent with generation of a parent magma with less or no garnet in the residue (lower pressure?) that could possibly reflect contributions of an enriched mantle source and/or of partial melting of the root of the overlying Pan-African orogenic belt. Input of mafic magmas derived from partial melting of an enriched mantle synchronous with the Pan-African tectono-metamorphic event is further constrained by two dated samples of type 1 (cumulate) and type 3 (calc-alkaline) amphibolites, with emplacement ages of 600 ± 4 Ma (sample NB14-11a) and 599 ± 6 Ma (sample NB14-11b). It should be noted that it is not possible to ascertain whether type 2 amphibolites, showing distinct chemistry close to E-MORB, are Pan-African or older owing to the absence of geochronological information for these rocks.

These results complement the study of the plutonic rocks near Ngaoundéré, just south of the studied area documenting high-K, hornblende-biotite and biotite $\pm$ muscovite granites, emplaced at ca. 615 ± 27 Ma and ca. 575 Ma, respectively (Tchameni et al., 2006). The geochemical signatures of the hornblende-biotite granites, notably the LILE enrichment and the negative Nb-Ta anomalies, have been taken as an evidence for an origin of these magmas by partial melting of an enriched mantle source followed by crustal contamination and fractional crystallisation. In contrast, based on their high Th content, enrichment in LREE and the presence of inherited monazite, biotite granites have been interpreted to reflect partial melting of the Pan-African orogenic crust (Tchameni et al., 2006). Similar signatures have been obtained for plutonic rocks of the Fomopea magmatic complex straddling the Banyo-

Tcholliré Shear Zone to the southwest of the studied area (Kwekam et al., 2010). U–Pb dates on zircon from a diorite and a quartz-monzodiorite give Pan-African ages of 620 ± 3 Ma and 613 ± 2 Ma, respectively. In addition, to major and trace elements, Sr–Nd isotopic data indicate mixing between a juvenile source and a Palaeoproterozoic to Archaean lower continental crust. These data are interpreted by Kwékam et al. (2010) to reflect partial melting of the mantle following delamination of the subcontinental lithospheric mantle beneath the Western and Central Cameroon Domain and inducing widespread partial melting of the Archaean-Paleoproterozoic basement. To the north of the Fomopea complex, the Mbengwi magmatic complex, intruding the North Cameroon Domain also displays similar petrological and geochemical characteristics (Mbassa et al., 2016). However, based on the low Mg#, LREE enrichment, and negative Eu anomaly, the high-K calc-alkaline magmas have been attributed by Mbassa et al. (2016) to partial melting of crustal sources including contributions of Neoproterozoic juvenile oceanic crust tectonically accreted during the Pan-African in the Central African Orogenic Belt with reworked Archaean to Paleoproterozoic crust.

The Neoproterozoic mafic magmas identified in the Mbé – Sassa-Mbersi region correspond to metabasic rocks with a cumulate character and to type 1 and 3 amphibolites. These metabasic rocks display differentiated REE patterns enriched in LREE and LILE with Nb, Ta, P, and Ti negative anomalies similar to the plutonic rocks but also to the metasedimentary rocks and the migmatitic intermediate to felsic gneisses. Accordingly, the geochemical signature of the migmatitic intermediate to felsic gneisses and of the plutonic rocks of the Central Cameroon Domain might reflect the characteristics of crustal rocks (arc crust, metasediments and/or continental basement) tectonically accreted to the Central African Orogenic Belt during the Pan-African rather than the composition of the underlying mantle. In this case, the only definite evidence for an enriched mantle underlying the Central African Orogenic Belt comes from the trace element signatures of the cumulate metabasic rocks and of the type 1 and 3 amphibolites. Following this reasoning, the E-MORB composition of the type 2 amphibolites might reflect either partial melting of a different part of the mantle during the Neoproterozoic or partial melting of the mantle during a preceding event of juvenile accretion (presumably the Paleoproterozoic). To choose between these propositions will require additional geochronological and isotopic tracing of these rocks.

7.3. Pan-African magmatic-tectonic-metamorphic evolution

Models proposed for the evolution of the Pan-African Central African Orogenic Belt invoked a polyphased tectonic record on the basis of relative chronology established by structural geology and absolute dating of plutonic rocks positioned relative to structures (Penaye et al., 1989; Toteu et al., 2001, 2004). Following this strategy, Toteu et al. (2004) identified a first phase D₁ of nappe emplacement followed by a second phase D₂ of E–W shortening associated with transposition of the shallow-dipping foliation into a subvertical one. As U–Pb ages are not different for these tectonic phases and range from ca. 635 Ma to ca. 615 Ma, Ngako and Njonfang (2011) grouped them into a single prolonged crustal thickening phase. A similar reasoning could be applied to the D₃ phase. Indeed, for example, the activity of the Banyo–Tcholliré Shear Zone was first considered to be limited to the time period between ca. 600 and ca. 580 Ma (Penaye et al., 1989; Toteu et al., 2001), but new U–Pb ages obtained on magmatic zircons from syn- to late-tectonic plutons emplaced in the Tcholliré region imply that it was already active from ca. 650 Ma to ca. 630 Ma (Nomo et al., 2017). The age of 651 ± 3 Ma obtained on tonalite (NG14-02), the oldest plutonic rock identified in the Mbé – Sassa-Mbersi area, further strengthen this proposition. The structural analysis presented in this paper is consistent with coeval development of the shallow-dipping S_{0/n} foliation and of the steep-dipping S_{n+1} schistosity in the presence of melt. The general NE-SW trend of the Tcholliré-Banyo Shear Zone, parallel to the azimuth of the regional S_{n+1} foliation suggests localization of this deformation phase. This proposition is consistent with the one of Ngako and Njonfang (2011) to consider that the shallow-dipping and steeply dipping foliations are both recording a period of crustal thickening. However, we nuance this model and advocate that coeval subvertical and shallow-dipping shear zones associated with a shallow-dipping mineral and stretching lineation suggest a finite strain ellipsoid in the constriction field with partitioning of the strike slip component along subvertical shear zones (Chardon et al., 2009; Fossen and Tikoff, 1998; Tikoff and Teyssier, 1994).

Thermodynamic modelling shows that the peak metamorphic conditions recorded in the garnet cores of metasediments (M₁; ca. 1.3 GPa for ca. 770 °C) was followed by an isothermal decompression down to ca. 0.8 GPa (M₂ retrograde event recorded in the garnet rims). These conditions are consistent with those reported by previous investigations that yielded peak pressures at 1.3–1.4 GPa from conventional geothermobarometry (Bouyo et al., 2013). Following the criteria of the continuity of the syn-migmatitic foliation (Brown, 1973; Vanderhaeghe, 2001, 2009), these migmatitic paragneisses classify as metatexites and represent former partially molten rocks. Garnet porphyroblasts are typically surrounded by a

quartzofeldspathic halo or are included in larger centimetre to decimetre size leucosome veins suggesting that garnet is a peritectic phase formed from biotite-dehydration melting in agreement with temperature estimates. These features indicate that partial melting and melt segregation occurred during deformation associated with the development of S_{n+1} . However, pristine magmatic textures are seldom preserved in leucosomes that are in most places affected by a solid-state fabric and even pinched and swelled into the S_{n+1} foliation. The youngest concordant zircon grains (rims with Th/U ratios < 0.12) from the garnet paragneiss (NB14-02) yields an average concordant date of 582 ± 4 Ma providing a minimum age for this high-grade metamorphism. These ages are consistent with previous zircon U–Pb data indicating 600–580 Ma for the timing of anatexis and deformation, and with Sm–Nd data on whole-rock–garnet pair from metapelite which gave an age of 600 ± 5 Ma (Toteu et al., 1987, 2001; Bouyo Houketchang et al., 2009; Bouyo et al., 2015). Nevertheless, it should be noted that zircon tends to crystallize with the melt phase during the retrograde path (Kelsey et al., 2008; Yakimchuk et al., 2014), which implies that these ages probably provide a minimum for the onset of melting. Such a protracted duration for high-temperature metamorphism and deformation in the presence of melt for several tens of Ma has been proposed for other orogenic belts (Vanderhaeghe et al., 1999; Harley, 2016; Guergouz et al., 2018; Turlin et al., 2018).

In order to account for the structural, petrologic, metamorphic and geochronologic data presented in this paper integrated with previously published data we propose that the Central Cameroon Domain has recorded lateral flow of a partially molten orogenic root in a similar way to what has been proposed for the Cenozoic Tibetan and the Proterozoic Grenville orogenic plateaus (Royden et al., 1997; Hodges, 2000; Vanderhaeghe and Teyssier, 2001; Vanderhaeghe, 2012; Turlin et al., 2018) or was described for the Archean Dharwar craton (Chardon and Jayananda, 2008) and for the Paleoproterozoic Finnish Svecofennides (Cagnard et al., 2007). This lateral flow is consistent with coeval vertical and shallow-dipping shear zone associated with a dominant shallow-dipping stretching direction. U–Pb dating of syntectonic plutons is consistent with an onset of this lateral flow around ca. 650 Ma and ongoing until 580 Ma in the presence of melt. Lateral flow of the orogenic crust is also coeval with the input of mantle-derived magmas as evidenced by the metabasites with emplacement ages of ca. 600 Ma. Retrogression associated with activation of NNE–SSW to E–W trending dextral shear zones such as the Central Cameroon Shear Zone marks the waning stage of the Pan-African orogeny in the Central Cameroon Domain. In the Mbé – Sassa-Mbersi region, the U–

Pb age of 573 ± 3 Ma obtained on magmatic zircon from a partially transposed pegmatitic granite in a dextral shear zone probably represents the last plutonic event of the waning stage of the Pan-African orogeny.

8. Summary and conclusion

The Mbé – Sassa-Mbersi area exposes a complex assemblage of metabasic rocks (amphibolites, hornblendites, metagabbros), paragneisses with calc-silicate layers grading into ubiquitous migmatitic intermediate to felsic gneisses. Paragneisses contain detrital zircon pointing to the contribution of Archean, Paleoproterozoic and Neoproterozoic sources. The youngest age obtained on a detrital core of 725 ± 12 Ma provides a maximum age for the deposition of the protolith of these paragneisses. At least some of the protoliths of the metabasic rocks have been emplaced during the Neoproterozoic as indicated by U–Pb ages on magmatic zircon from amphibolites at 600 ± 4 and 599 ± 6 Ma.

These metamorphic rocks display a penetrative shallow-dipping syn-migmatitic foliation partially to totally transposed in a NE–SW trending steep-dipping foliation also delineated by leucosomes and associated with sinistral kinematic indicators. These fabrics bear a shallow-dipping mineral lineation that records a dominant NE–SW stretching direction. The development of this ductile fabric occurred under granulite to amphibolite facies metamorphic conditions as constrained by a peak at ca. 1.3 GPa and ca. 770 °C, followed by isothermal decompression down to ca. 0.8 GPa obtained by thermodynamic modelling on a migmatitic garnet paragneiss. The same garnet paragneiss contains zircon with U–Pb ages spreading along Concordia from ca. 640 Ma to ca. 565 Ma and yielding a well-constrained minimum age for metamorphic rims at 582 ± 4 Ma. Localization of high-grade deformation is marked by the development of the Tcholliré-Banyo Shear Zone characterized by mutually cross-cutting subvertical and shallow-dipping mylonitic to ultramylonitic shear zones associated with sinistral and top-to-the SW kinematic criteria respectively. The high-grade fabric is cross-cut by lower-grade localized E–W trending subvertical dextral shear zones.

Intrusive, partially transposed plutonic rocks display a composition spanning from monzodiorite to granite, showing I-type chemical signature. All these plutonic rocks show a differentiated REE pattern associated with enrichment in LREE and LILE and negative

anomalies in Nb, Ta, P and Ti. Nevertheless, three main series are distinguished; (i) tonalites-trondhjemites with a magnesian medium-K signature, (ii) hornblende-biotite granites with a magnesian high-K signature and biotite-granite with a ferroan shoshonitic signature; that might reflect a variety of sources and/or of the conditions of partial melting, but discussing more thoroughly this point will require some additional isotopic data. The emplacement of these different magmatic rocks occurred over a period of more than 80 Ma as constrained by zircon U–Pb data at 651 ± 3 Ma (medium-K tonalite), 599 ± 2 Ma (high-K hornblende-biotite granite), and 573 ± 2 Ma (pegmatite dyke partially transposed in dextral shear zone).

Based on these data, we propose that the Central Cameroon Domain exposed in the Mbé – Sassa-Mbersi region represents the exhumed mid- to lower part of the former orogenic root of the Pan-African Central African Orogenic Belt. This root has undergone protracted syn-migmatitic deformation, horizontal stretching, sinistral shearing and emplacement of mafic to felsic calc-alkaline magmas from 650 to 580 Ma associated with exhumation. The waning stage of the Pan-African orogeny is marked in this region by the emplacement of syn-tectonic pegmatitic granite at ca. 575 Ma partially transposed in subvertical E-W trending retrogressive dextral shear zones.

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Figure captions

Figure 1. (a) Tectonic map of Western Gondwana showing the position of the Central African Orogenic Belt pinched in between the West-African craton, the Congo craton and the Sahara metacraton (modified after Küster and Liégeois, 2001; Toteu et al., 2004). The position of the map at the scale of Africa is shown in the inset. (b) Geology of the Central African Orogenic in Cameroon and southern Chad (modified after Toteu et al., 2001; Pinna et al., 1994; Toteu et al., 2004). The location of the map is shown by a grey rectangle on figure 1a. Abbreviation: CD = Central Domain; SZ = Shear Zone.

Figure 2. Geodynamic models for the tectonic-magmatic evolution of the Central African Orogenic Belt. (a) The “crustal reworking” model considers that the Central African Orogenic Belt essentially corresponds to reworked pre-existing Archaean and Paleoproterozoic cratons after inversion of a continental rift. In this model, magmatism is dominantly issued from partial melting of the crust triggered by delamination of the subcontinental lithospheric mantle. (b) The “magmatic-tectonic accretion” model considers that the Central African Orogenic Belt is made of accreted terranes (magmatic arc, back-arc, ophiolite) along an active margin, which does not preclude the presence of reworked blocks of the former cratons. In this model, magmatism is attributed to both, crustal- and mantle- sources.

Figure 3. Geological map of the Mbé–Sassa–Mbersi area (position indicated by a grey rectangle on figure 1b).

Figure 4. Geological map of the Ndong Benue area. Samples described for petrology, geochemistry and/or geochronology are indicated by white letters and numbers.

Figure 5. Migmatitic intermediate to felsic gneisses of the Ndong Benue area. (a) and (b) show amphibolite layers boudinaged and transposed in the foliation of migmatitic intermediate to felsic gneisses. (c) Detail of a migmatitic intermediate gneiss with alternations of leucosomes and mesosomes defining the syn-migmatitic foliation. (d) Amphibolites cross-cut by intrusive foliated tonalite. (e) Gneisses with an intermediate to felsic composition cross-cut by a pinched and swelled granitic dike partially transposed into the foliation. (f) Migmatitic intermediate to felsic gneisses partially transposed into NE-SW trending sinistral shear zones.

Figure 6. Metabasites of the Mbé – Sassa-Mbersi area. (a) Migmatitic garnet amphibolite of the Karna quarry with tonalitic leucosome underlining the syn-migmatitic foliation. (b) Metagabbro of the Ndgon Benue area with tonalite filling interboudins' neck.

Figure 7. Paragneisses of the Ndong Benue area. (a) Alternations of metagreywackes and metapelites delineating a $S_{0/n}$ foliation and folds with an axial planar syn-migmatitic S_{n+1} foliation. (b) Migmatitic garnet paragneiss with leucosomes in the XZ plane of deformation showing a sigmoid shape consistent with a sinistral sense of shear. (c) Migmatitic paragneiss with folded discordant leucosome and an axial planar syn-migmatitic foliation. (d) Migmatitic paragneiss with partially transposed discordant leucosome in textural continuity with concordant leucosome. (e) Migmatitic paragneiss with a syn-migmatitic S_{n+1} foliation underlined by mesosome/leucosome alternations superimposed on the transposed $S_{0/n}$ foliation marked by metagreywackes/metapelites alternations. (f) Granitic vein transposed into the S_{n+1} foliation of a migmatitic paragneiss.

Figure 8. Composite foliation of the intermediate to felsic gneisses. (a) Foliation S_{n+1} marked by alternations of mica-rich and quartz-feldspar-rich layers, both comprising feldspar porphyroclasts. (b) Amphibolite boudin wrapped in the S_{n+1} gneissic foliation. (c) Metagabbro boudin wrapped in the S_{n+1} gneissic foliation. (d) Relictual S_n foliation preserved from transposition. (e) Partially transposed granitic vein discordant on the S_{n+1} gneissic foliation marked by alternations of porphyroclast-rich and porphyroclast-poor layers. (f) Pinched-and-swelled pegmatitic layer transposed in a mylonitic foliation including feldspar porphyroclasts.

Figure 9. Biotite granite of the Ndong Benue area. (a) Granitic dikes with sharp contacts discordant on the S_{n+1} foliation of the host intermediate gneiss. (b) Granitic veins concordant to the S_{n+1} foliation of the host intermediate gneiss with a fabric grading from magmatic to solid-state. (c) Granitic veins concordant and discordant to the S_{n+1} foliation of the host intermediate gneiss with a solid-state fabric. (d) Epidote veins with diffuse boundaries cross-cutting the S_{n+1} foliation of an amphibolite at the contact of a biotite granite.

Figure 10. Mylonitic amphibolites of the Karna quarry. (a) Overview of the quarry. (b) Sheath folds separated by dominantly steep-dipping mylonitic foliation. Location indicated by

a white rectangle in Fig. 9a. (c) Shallow-dipping syn-migmatitic foliation in an amphibolite. (d) Shallow-dipping cataclastic fabric in an amphibolite.

Figure 11. Ndom Benue mylonitic shear zone. (a) Shallow dipping mylonitic foliation marked by alternating layers of intermediate and felsic gneisses. (b) Feldspar porphyroclasts wrapped in the mylonitic foliation with a sigmoid shape in the XZ plane of deformation consistent with a top-to-the WSW. (c) Ultramylonitic foliation bearing a WSW-ESE trending stretching lineation. (d) Sheath folds with an axis parallel to the WSW-ESE trending lineation.

Figure 12. Dextral shear zones of the Ndong Benue area. (a) Deflection of the S_{n+1} foliation into a 10-cm thick mylonitic shear zone consistent with a dextral sense of shear. (b) Discordant granitic vein in a position of a tension gash relative to a dextral shear zone.

Figure 13. Photomicrographs of selected metamorphic rocks from the Mbé – Sassa-Mbersi area. (a) hornblendite (Mayo Lou); (b) amphibolite (Ndong Benue); (c) garnet amphibolite (Mayo Lou); (d) Garnet-sillimanite gneiss (Ndong Benue); (e) tonalitic orthogneiss (Mayo Mbanna); and (f) leucogneiss (Falaise). See text for further explanation.

Figure 14. $\text{Fe}_2\text{O}_3 + \text{CaO} + \text{TiO}_2$ vs. Al_2O_3 plot (La Roche, 1965) for the metamorphic rocks of the Mbé – Sassa-Mbersi area. Dark grey solid line = igneous trend (ga = gabbro, di = diorite, gd = granodiorite, gr = granite).

Figure 15. (a) $\text{MgO} - \text{FeO}^*$; (b) $\text{CaO} - \text{SiO}_2$; (c) $\text{FeO}^*/\text{MgO} - \text{SiO}_2$; and (d) $\text{Th/Yb} - \text{Nb/Yb}$ for the metabasic rocks of the Mbé – Sassa-Mbersi area. FeO^* = total iron as FeO ; tholeiitic/calc-alkaline divide from Miyashiro (1974); mantle array, N-MORB, E-MORB and OIB from Pearce (1996). Subducted sediments from Pearce (2008).

Figure 16. REE patterns normalized to chondrite (Evensen et al., 1978) and multi-element plot normalized to the primitive mantle (Sun and Macdonough, 1989) for the metabasic rocks of the Mbé – Sassa-Mbersi area. (a) and (b) cumulate rocks (hornblendite, metagabbro and type 1 amphibolite); (c) and (d) type 2 amphibolites; (e) and (f) type 3 amphibolites. See text for further explanation.

Figure 17. REE patterns normalized to chondrite (Evensen et al., 1978) and multi-element plot normalized to the primitive mantle (Sun and Macdonough, 1989) for the garnet gneisses and calc-silicate rocks (a and b), and for the intermediate to felsic orthogneisses (c and d). NASC (North American Shale Composite) from Gromet et al. (1984); Phanerozoic graywackes from Taylor and McLennan (1985).

Figure 18. Classification diagrams for the plutonic rocks of the Mbé – Sassa-Mbersi area: (a) Q'–ANOR; (b) A/NK vs. A/CNK [$\text{Al}_2\text{O}_3/(\text{Na}_2\text{O}+\text{K}_2\text{O})$ vs. $\text{Al}_2\text{O}_3/(\text{CaO}+\text{Na}_2\text{O}+\text{K}_2\text{O})$]; (c) $\text{FeO}/(\text{FeO}+\text{MgO})$ vs. SiO_2 ; (d) K_2O vs. SiO_2 ; and Rb vs. Y+Nb (after Streckeisen and Le Maitre, 1979; Whalen and Frost, 2013; Shand, 1943; Frost et al., 2001; Peccerillo and Taylor, 1976; and Pearce et al., 1984).

Figure 19. REE patterns normalized to chondrite (Evensen et al., 1978) and multi-element plot normalized to the primitive mantle (Sun and Macdonough, 1989) for the plutonic rocks of the Mbé – Sassa-Mbersi area. (a) and (b) microgranular enclaves; (c) and (d) hornblende-biotite granite; (e) and (f) tonalite and trondhjemite; (g) and (h) biotite granite.

Figure 20. Perple_X P – T pseudosection for the metasedimentary rock sample NB14-01. M₁: peak metamorphic conditions determined from garnet core composition; M₂: retrograde conditions determined from garnet rim composition. Isopleths of garnet also shown.

Figure 21. Zircon U–Pb diagrams for some metamorphic and magmatic rocks from the Mbé – Sassa-Mbersi area: (a) and (b) Concordia diagram for garnet gneiss sample NB14-02; (c) distribution plot of $^{206}\text{Pb}/^{238}\text{U}$ (grains <1000 Ma) and $^{207}\text{Pb}/^{235}\text{U}$ (grains >1000 Ma) ages for the same garnet gneiss; (d) and (e) Concordia diagrams for garnet amphibolite sample NB14-11a and NB14-11b; (f) Concordia diagram for the tonalite sample NG14-02; (g) Concordia diagram for the hornblende-biotite granite sample M13-01D; and (h) Concordia diagram for pegmatite granite sample NB14-09.

Figure 1

(a) Crustal reworking

(b) Magmatic-tectonic accretion

Figure 4

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Figure 21 continued

Table 13. Major (wt.%) and trace element (ppm) composition of metabasic rocks from the Mbé – Sassa-Mbersi area.

Sample	NB14 05	NB14 44	ML14 08	NB14 07a	NB14 11c	NB14 11d	NB14 11b	ML14 01a	ML14 04
Type	hbd	hbd	hbd	mga	mga	amp	amp	amp	amp
SiO ₂	46.57	49.20	51.64	47.28	50.45	41.21	42.15	42.86	50.17
Al ₂ O ₃	11.28	4.12	4.01	16.14	6.16	14.90	15.53	12.23	14.27
Fe ₂ O ₃ ^{tot}	12.24	13.49	10.59	10.49	9.99	14.64	14.47	13.50	12.19
MnO	0.21	0.25	0.20	0.14	0.19	0.17	0.22	0.12	0.20
MgO	11.95	16.00	17.82	9.50	15.21	9.54	8.38	11.76	7.25
CaO	12.01	12.75	12.27	10.09	11.91	9.61	9.71	12.43	10.39
Na ₂ O	1.63	0.50	0.46	3.04	1.19	2.01	1.96	1.37	3.06
K ₂ O	1.39	0.31	0.38	1.09	0.65	1.65	2.11	1.26	1.03
TiO ₂	1.16	0.61	0.53	1.22	0.55	2.62	2.23	1.30	1.19
P ₂ O ₅	0.16	0.06	ld	ld	0.11	0.31	0.48	0.89	0.25
LOI	2.25	2.68	2.33	2.08	3.21	2.73	2.75	1.79	0.71
Total	100.84	99.96	100.24	101.07	99.61	99.38	99.99	99.51	100.71
Ba	296	39	60	335	157	924	1269	258	321
Co	56	64	67	51	66	54	51	51	40
Cr	155	1147	691	254	1457	104	118	523	225
Ga	16.4	12.6	9.9	19.8	11.1	23.0	26.1	28.4	22.2
Hf	3.1	2.1	2.4	1.2	2.3	2.8	3.1	6.0	2.5
Nb	4.1	1.1	0.8	3.0	2.9	8.3	9.9	8.3	10.8
Ni	50	309	341	97	230	30	65	172	96
Rb	28	5	9	19	11	37	47	22	11
Sc	56	42	55	51	43	43	39	33	35
Sn	1.5	1.7	1.3	1.3	1.1	2.4	3.2	3.4	3.0
Sr	210	114	84	709	92	543	671	137	873
Ta	0.3	0.1	0.1	0.2	0.2	0.4	0.4	0.4	0.6
Th	1.8	0.1	0.6	0.1	0.6	0.4	0.5	5.8	0.4
U	0.3	0.1	0.2	0.1	0.3	0.1	0.1	0.9	0.1
V	366	218	178	298	189	331	289	243	297
W	0.3	0.3	0.6	0.5	-	0.5	0.3	0.5	-
Y	33.8	17.1	16.9	23.4	16.9	39.9	47.0	13.0	32.5
Zn	101	175	104	99	89	139	184	253	137
Zr	107	49	61	27	71	69	91	219	74
La	15.21	8.52	7.70	6.02	11.03	18.21	24.08	50.87	30.61
Ce	37.58	29.01	26.13	22.35	29.51	54.63	72.78	109.10	86.47
Pr	5.29	4.95	4.18	4.32	4.31	8.66	11.58	12.81	12.30
Nd	23.82	24.76	19.62	23.74	19.19	42.53	54.41	49.68	52.37
Sm	6.03	6.35	4.85	6.46	4.52	10.86	13.11	8.45	10.87
Eu	1.65	1.53	1.00	1.67	1.12	2.88	3.37	1.85	2.64
Gd	5.79	4.76	3.91	5.27	3.90	9.46	11.17	6.25	7.95
Tb	0.93	0.66	0.57	0.78	0.57	1.35	1.58	0.74	1.12
Dy	6.09	3.64	3.39	4.60	3.33	7.96	9.32	3.42	6.20
Ho	1.33	0.69	0.66	0.91	0.66	1.59	1.84	0.53	1.20
Er	3.57	1.67	1.70	2.33	1.71	3.97	4.59	1.15	3.07
Tm	0.53	0.23	0.24	0.32	0.24	0.53	0.61	0.12	0.43
Yb	3.64	1.48	1.56	2.12	1.56	3.24	3.78	0.72	2.79
Lu	0.56	0.22	0.23	0.31	0.23	0.47	0.56	0.10	0.42

Table 13. (Continued)

Sample	NB14 11a	NB14 08c	NB14 11e	NB14 08b	N14 01a-2	NB14 10	N14 01a-1
Type	grt amp	grt amp	amp	grt amp	amp	grt amp	amp
SiO ₂	45.22	46.45	47.35	51.43	51.59	52.37	53.87
Al ₂ O ₃	19.78	15.05	17.85	13.29	16.24	13.55	17.14
Fe ₂ O ₃ ^{tot}	11.90	16.57	10.34	16.06	9.38	16.83	8.40
MnO	0.14	0.19	0.15	0.23	0.15	0.20	0.13
MgO	3.97	7.72	4.90	3.70	3.93	4.92	3.45
CaO	9.18	7.53	7.77	9.60	6.55	8.61	5.40
Na ₂ O	3.82	2.61	3.65	1.39	3.94	0.84	4.41
K ₂ O	1.31	0.75	2.27	0.25	3.38	0.27	3.62
TiO ₂	1.67	1.72	1.44	2.45	1.45	1.66	1.33
P ₂ O ₅	1.17	0.22	0.64	0.25	0.95	0.18	0.77
LOI	2.49	2.04	2.24	1.15	1.42	0.76	1.50
Total	100.65	100.82	98.61	99.78	98.99	100.18	100.02
Ba	932	280	1181	69	2988	38	3173
Co	29	55	30	52	28	55	27
Cr	17	157	40	75	592	194	690
Ga	26.5	19.9	26.4	20.7	25.6	17.1	26.3
Hf	4.2	3.0	6.8	4.6	8.3	3.0	8.5
Nb	7.4	7.9	12.2	12.3	12.1	8.7	12.1
Ni	7.8	102	19	58	357	131	415
Rb	32	18	70	6	55	6	55
Sc	16	49.8	23.5	40.6	18.0	46.2	13.6
Sn	2.0	4.6	3.3	3.5	4.1	1.8	3.7
Sr	1318	206	954	290	1691	140	1597
Ta	0.3	0.6	1.0	1.1	0.6	0.7	0.6
Th	0.5	0.6	3.9	1.0	5.6	0.4	4.2
U	0.1	0.2	0.6	0.4	0.9	0.3	0.8
V	165	302	212	303	161	311	144
W	-	0.7	ld	1.4	1.6	1.1	1.9
Y	32.1	22.8	30.0	35.1	34.8	27.1	26.4
Zn	135	181	141	132	156	147	137
Zr	187	103	293	175	395	108	376
Sample	NB14 11a	NB14 08c	NB14 11e	NB14 08b	N14 01a-2	NB14 10	N14 01a-1
La	35.27	9.98	59.91	13.73	90.21	9.72	65.76
Ce	91.73	25.76	128.40	34.46	199.90	24.77	147.60
Pr	12.42	3.56	15.37	5.02	24.82	3.52	18.13
Nd	54.45	15.77	59.84	22.90	98.10	16.37	72.20
Sm	11.04	3.98	11.46	6.27	17.62	4.40	12.80
Eu	2.94	1.27	2.82	1.98	4.28	1.62	3.04
Gd	8.63	4.00	8.32	6.55	11.71	4.70	8.65
Tb	1.18	0.67	1.13	1.06	1.47	0.77	1.09
Dy	6.48	4.36	6.12	6.69	7.44	4.93	5.60
Ho	1.24	0.93	1.16	1.40	1.35	1.04	1.01
Er	3.06	2.44	2.91	3.57	3.34	2.70	2.57
Tm	0.40	0.35	0.39	0.50	0.43	0.39	0.33
Yb	2.48	2.37	2.57	3.35	2.78	2.55	2.15
Lu	0.37	0.35	0.37	0.49	0.42	0.40	0.33

hbd = hornblende; mga = metagabbro; amp = amphibolite; grt = garnet.

Table 11. Major (wt.%) and trace element (ppm) composition of metasedimentary and metavolcanic rocks from the Mbé – Sassa-Mbersi area.

Sample	NB14 01b	NB14 26ab	MM14 01	NB14 01a	NB14 02	N14 01c	NB14 27a	NB14 27b
Type	grt gn	grt gn	grt gn	grt gn	grt gn	gn	csr	csr
SiO ₂	53.04	62.58	62.91	64.38	66.08	71.70	41.34	46.19
Al ₂ O ₃	21.58	15.51	15.63	15.25	14.80	12.71	16.07	8.13
Fe ₂ O ₃ ^{tot}	6.31	8.73	8.28	9.17	7.26	5.47	9.30	8.74
MnO	0.07	0.18	0.15	0.17	0.12	0.08	0.16	0.24
MgO	2.63	3.91	3.28	3.08	2.41	1.17	7.88	8.22
CaO	5.28	2.26	3.17	2.31	2.67	1.60	16.32	19.79
Na ₂ O	4.49	3.12	2.97	1.91	2.63	4.46	0.55	1.56
K ₂ O	3.45	1.86	1.49	2.24	1.74	1.46	1.69	0.88
TiO ₂	1.50	0.96	0.99	1.10	1.01	0.50	0.80	0.74
P ₂ O ₅	0.86	0.20	0.21	0.17	0.06	0.07	1.31	4.10
LOI	1.55	0.54	0.55	0.74	0.99	1.22	3.87	1.60
Total	100.75	99.84	99.64	100.51	99.77	100.44	99.30	100.19
Ba	2513	570	597	727	726	750	805	465
Be	1.2	0.7	0.8	0.7	0.6	1.0	1.6	2.0
Co	16.0	25.3	26.2	24.9	20.1	16.0	23.6	28.5
Cr	19	440	498	120	241	1247	240	817
Cs	1.1	0.5	0.2	1.3	0.8	0.1	0.2	0.2
Ga	30.5	18.8	17.9	20.1	19.4	17.5	32.8	23.6
Hf	8.3	4.9	5.3	6.4	8.7	17.3	10.1	5.6
Mo	-	33.1	40.5	0.6	19.1	138.3	24.8	87.9
Nb	15.2	9.2	9.6	13.1	14.1	7.7	56.7	22.7
Ni	15.8	248	270	61	134	732	153	483
Rb	101	55	40	82	68	28	57	37
Sc	5.6	23.7	21.0	23.7	16.8	5.4	19.9	21.6
Sn	0.8	0.9	2.9	1.5	1.0	2.9	7.7	4.0
Sr	1348	303	504	205	355	406	1672	895
Ta	1.3	0.7	0.4	1.2	1.2	0.2	4.5	1.6
Th	2.1	6.0	3.6	9.8	23.3	5.7	12.5	12.6
U	0.7	0.9	0.3	1.5	1.5	0.5	2.7	3.5
V	102	160	128	170	138	37	80	93
W	0.9	1.1	0.9	1.0	1.0	3.1	1.0	2.4
Y	14.6	38.0	34.4	38.4	26.9	28.4	64	103
Zn	117	136	104	119	104	110	147	133
Zr	395	183	209	242	347	695	413	191
La	31.54	25.91	24.26	33.96	62.49	46.19	114.20	292.20
Ce	76.35	55.79	52.48	72.43	126.30	104.70	300.70	703.40
Pr	10.53	6.87	6.52	8.60	13.85	12.56	43.66	97.19
Nd	45.54	27.80	26.23	32.86	50.46	51.29	200.10	386.00
Sm	11.06	5.98	5.69	6.77	8.60	10.32	42.37	70.19
Eu	2.88	1.47	1.60	1.64	1.78	2.36	11.88	14.56
Gd	7.54	5.64	5.34	6.32	6.17	8.47	30.21	47.60
Tb	0.83	0.96	0.90	1.05	0.86	1.14	3.80	5.77
Dy	3.61	6.43	5.84	6.80	5.04	6.22	17.86	26.74
Ho	0.54	1.42	1.29	1.45	1.02	1.19	2.78	4.15
Er	1.22	3.86	3.47	3.89	2.77	2.93	5.76	8.82
Tm	0.14	0.57	0.52	0.58	0.41	0.38	0.61	0.91
Yb	0.91	3.94	3.58	3.98	2.75	2.55	3.38	5.16
Lu	0.13	0.61	0.55	0.60	0.42	0.41	0.44	0.69

Fe₂O₃^{tot} = total iron as Fe³⁺; LOI = lost on ignition; - = below detection limit; gn = gneiss; csr = calc-silicate rock; grt = garnet.

Table 12. Major (wt.%) and trace element (ppm) composition of intermediate to felsic orthogneiss from the Mbé – Sassa-Mbersi area.

Sample	N14 01b	K14 01	NB14 03b	MM14 05	NB14 10a	NB14 07b	NB14 03	CK09 01	NFA 02
Type	qz-mzd	qz-mzd	qz-mzd	qz-mzd	qz-mz	ton	mzgr	syegr	syegr
SiO ₂	57.18	57.32	57.42	58.74	62.44	67.55	73.70	74.82	76.35
Al ₂ O ₃	15.54	15.68	14.79	17.28	16.67	15.87	14.15	13.37	13.32
Fe ₂ O ₃ ^{tot}	9.22	8.49	6.43	7.45	4.87	3.89	2.20	0.51	0.63
MnO	0.10	0.14	0.13	0.12	0.07	0.05	0.05	0.05	0.02
MgO	2.98	4.64	3.06	3.26	2.06	1.84	0.50	0.03	0.06
CaO	5.71	6.69	11.52	5.60	3.17	4.27	2.13	1.01	0.66
Na ₂ O	4.12	2.99	2.46	3.87	3.89	4.40	3.48	4.06	3.90
K ₂ O	1.79	1.90	2.38	1.97	3.66	1.45	3.58	4.33	4.99
TiO ₂	1.98	0.68	0.78	0.77	0.73	0.40	0.24	0.04	0.03
P ₂ O ₅	0.46	0.20	0.17	0.30	0.28	0.11	0.07	-	-
LOI	0.71	0.85	1.68	1.06	2.86	0.99	0.47	0.35	0.29
Total	99.80	99.58	100.81	100.42	100.10	100.82	100.56	98.57	100.25
Ba	645	613	504	658	1924	620	1067	24	187
Be	1.7	0.9	2.6	2.6	1.8	1.2	1.2	4.3	5.8
Co	28.6	25.2	17.7	23.7	11.2	12.1	4.1	0.5	1.7
Cr	345	206	92	399	18	47	154	51	172
Cs	1.0	1.0	0.9	2.9	0.4	0.3	0.4	4.8	5.0
Ga	23.7	18.3	21.4	24.6	20.0	22.6	17.3	19.3	25.1
Hf	5.7	2.7	4.7	3.5	5.2	2.8	3.3	2.6	3.8
Mo	37.2	2.9	1.8	40.6	-	-	17.2	3.0	19.3
Nb	15.4	4.6	11.7	6.6	5.3	3.4	4.2	15.6	9.1
Ni	217	46	43	235	13.8	25	92	33	101
Rb	48	62	83	83	76	45	82	122	311
Sc	8.7	25.5	15.1	18.9	8.9	8.9	3.9	2.3	2.8
Sn	2.6	0.8	4.5	2.7	1.9	1.7	1.1	1.5	5.3
Sr	689	465	804	705	751	672	366	34	71
Ta	1.2	0.3	1.1	0.4	0.3	0.2	0.3	3.7	1.1
Th	5.4	4.8	11.6	4.4	1.7	3.6	8.2	7.0	18.1
U	0.8	0.6	4.1	0.6	0.3	0.2	1.0	22.9	4.4
V	140	141	118	128	79.4	58	15.1	0.9	2.1
W	1.1	0.4	1.7	1.2	-	-	0.5	0.3	0.7
Y	15.3	19.1	27.7	19.0	14.4	7.2	15.8	30.6	24.4
Zn	124	100	92	113	71	63	45	22	27
Zr	233	94	171	135	221	99	103	62	61
La	37.49	18.23	33.19	28.33	33.70	24.74	22.80	2.87	13.02
Ce	82.32	39.61	73.58	58.94	67.77	47.51	44.79	6.38	27.20
Pr	9.91	4.92	8.68	7.19	7.74	5.20	4.98	0.85	3.26
Nd	38.44	19.82	32.87	28.53	28.70	18.54	18.00	3.71	11.67
Sm	7.23	4.25	6.64	5.87	5.07	3.13	3.32	1.61	3.30
Eu	2.03	1.13	1.40	1.53	1.49	0.84	0.86	0.35	0.22
Gd	5.27	3.65	5.66	4.65	3.82	2.31	2.75	2.16	3.01
Tb	0.69	0.55	0.85	0.65	0.51	0.31	0.43	0.49	0.54
Dy	3.54	3.37	5.22	3.61	2.83	1.60	2.62	3.74	3.42
Ho	0.60	0.72	1.03	0.70	0.55	0.28	0.54	0.86	0.71
Er	1.35	1.93	2.75	1.84	1.38	0.67	1.50	2.74	1.93
Tm	0.16	0.28	0.39	0.26	0.20	0.09	0.23	0.49	0.30
Yb	0.90	1.98	2.60	1.79	1.22	0.55	1.59	3.70	2.15
Lu	0.13	0.30	0.39	0.27	0.19	0.08	0.25	0.61	0.33

qz-mzd = quartz monzodiorite; qz-mz = quartz monzonite; ton = tonalite; mzgr = monzogranite; syegr = syenogranite.

Table 14. Major and trace element compositions of plutonic rocks from the Mbé – Sassa-Mbersi area.

Sample	SM13	SM13	NB14	SM13	L14	NG14	NB14	CK13	NB14
Type	3b	1a	12	3c	03	02	08a	6c	20
	me	me	me	me	ton	ton	trond	hb-gr	hb-gr
SiO ₂	49.14	52.49	54.16	65.63	60.71	66.22	74.05	56.70	57.21
Al ₂ O ₃	15.24	18.62	16.56	14.96	16.26	16.19	14.66	15.72	14.55
Fe ₂ O ₃ ^{tot}	11.12	8.04	7.57	4.26	7.36	3.48	1.53	7.21	6.70
FeO _{tot}	10.01	7.23	6.81	3.83	6.62	3.13	1.38	6.49	6.03
MnO	0.17	0.13	0.11	0.06	0.13	0.06	0.03	0.11	0.14
MgO	6.19	2.87	4.61	1.55	3.16	1.72	0.60	4.96	2.89
CaO	8.90	5.62	6.38	3.14	4.68	4.27	1.97	6.23	11.04
Na ₂ O	3.00	4.32	3.93	3.51	3.21	4.55	5.04	3.77	2.19
K ₂ O	1.94	3.87	2.03	4.20	1.29	1.84	1.76	2.14	3.16
TiO ₂	1.83	1.00	1.11	0.65	0.68	0.46	0.18	1.01	0.73
P ₂ O ₅	0.51	0.64	0.43	0.27	0.24	0.13	0.05	0.39	0.15
LOI	1.17	1.05	2.38	0.72	2.01	0.57	0.99	0.93	1.27
Total	99.21	98.64	99.26	98.94	99.73	99.49	100.84	99.18	100.02
Ba	1624	2520	1276	1633	572	413	931	1103	620
Be	1.4	2.2	1.1	2.4	1.8	1.0	0.6	2.0	2.4
Co	34.0	14.9	26.8	9.9	20.9	9.6	3.6	25.7	21.9
Cr	83	53	104	96	355	18	17	215	411
Cs	1.4	2.0	0.3	1.9	1.5	0.6	0.2	1.8	1.1
Ga	22.0	25.2	22.7	21.8	21.9	18.5	17.1	21.1	20.5
Hf	6.0	9.0	2.2	5.7	5.0	3.7	1.9	4.5	4.7
Mo	1.5	1.0	ld	5.6	31.5	0.8	ld	3.1	39.0
Nb	14.8	16.0	5.7	12.3	7.0	2.4	1.4	8.4	12.3
Ni	18.2	17.0	52.7	47.3	193.6	13.4	7.5	104.9	239.6
Rb	61	127	37	114	64	38	28	52	116
Sc	34.2	12.1	16.9	7.8	17.5	6.6	3.3	17.3	16.2
Sn	2.4	2.8	1.3	4.3	2.2	0.7	0.7	1.9	5.0
Sr	1013	1541	1039	696	575	525	644	918	884
Ta	1.1	1.2	0.4	1.2	0.4	0.2	0.0	0.6	1.0
Th	6.3	15.8	1.2	21.1	11.1	3.2	0.2	1.4	13.1
U	1.4	2.2	0.2	3.0	1.7	0.8	0.3	2.5	3.4
V	280.0	104.7	155.4	66.6	103.8	54.9	16.2	147.0	115.1
W	0.3	0.3	0.4	0.5	0.9	ld	ld	0.4	2.6
Y	36.7	31.3	16.5	18.7	19.3	8.4	3.6	19.4	30.3
Zn	116	119	98	57	114	56	32	96	99
Zr	240	386	75	215	190	128	59	184	158
La	42.10	94.11	32.54	60.76	40.08	9.95	6.54	31.06	33.31
Ce	99.81	178.70	67.39	112.60	81.95	22.59	12.41	67.47	69.25
Pr	12.85	20.12	8.21	12.39	9.50	3.21	1.42	8.39	8.03
Nd	54.35	73.82	32.57	43.74	35.69	13.48	5.31	34.40	30.30
Sm	11.12	12.92	6.15	7.63	6.40	2.75	0.97	6.52	6.11
Eu	2.91	3.33	1.98	1.58	1.45	0.83	0.45	1.74	1.29
Gd	8.65	9.26	4.48	5.29	4.79	2.10	0.79	4.86	5.26
Tb	1.25	1.22	0.60	0.70	0.65	0.29	0.12	0.66	0.83
Dy	6.81	6.22	3.31	3.63	3.71	1.59	0.67	3.64	5.23
Ho	1.29	1.09	0.64	0.63	0.74	0.31	0.13	0.67	1.12
Er	3.48	2.94	1.61	1.71	1.95	0.78	0.34	1.80	3.11
Tm	0.51	0.41	0.22	0.24	0.27	0.11	0.05	0.26	0.47
Yb	3.37	2.68	1.41	1.59	1.86	0.77	0.32	1.75	3.19
Lu	0.50	0.41	0.21	0.23	0.28	0.13	0.05	0.27	0.51

Table 14. (Continued)

Sample	M13	NB14	M13	L14	NB14	MM14
Type	1c	04	3c	01	40	07
Type	hb-gr	hb-gr	bt gr	bt gr	bt gr	bt gr
SiO ₂	59.45	65.81	68.84	68.88	72.22	72.44
Al ₂ O ₃	16.75	14.38	14.02	15.17	13.83	14.18
Fe ₂ O ₃ ^{tot}	5.83	4.81	3.53	3.03	1.87	1.76
FeO _{tot}	5.25	4.33	3.18	2.73	1.68	1.58
MnO	0.09	0.09	0.04	0.03	0.03	0.03
MgO	2.50	2.06	0.66	0.73	0.42	0.37
CaO	4.34	3.15	1.66	2.11	1.36	1.36
Na ₂ O	4.32	2.86	2.79	3.33	3.10	3.20
K ₂ O	3.51	3.77	6.05	5.56	5.28	5.52
TiO ₂	0.93	0.61	0.63	0.52	0.27	0.24
P ₂ O ₅	0.42	0.16	0.22	0.17	0.07	0.08
PF	0.88	2.36	0.48	1.16	1.09	0.37
Total	99.02	100.07	98.92	100.69	99.53	99.54
Ba	1463	1132	1143	1519	1101	976
Be	3.3	1.3	1.7	2.0	1.4	1.5
Co	14.4	14.5	4.5	8.1	4.0	3.1
Cr	51	77	58	507	149	115
Cs	3.5	0.4	0.7	0.9	0.5	0.5
Ga	24.6	19.6	25.8	22.2	18.2	19.7
Hf	8.1	5.0	14.4	10.9	6.1	4.7
Mo	2.8	0.6	3.2	55.5	17.4	16.5
Nb	16.4	10.7	25.3	10.3	9.0	11.8
Ni	26.7	35.0	27.5	290.0	86.2	68.2
Rb	110	122	228	182	185	199
Sc	9.6	10.0	4.0	3.7	3.1	3.0
Sn	2.9	1.9	6.5	3.6	2.1	1.4
Sr	989	408	273	365	226	241
Ta	2.1	0.9	1.3	0.4	0.5	0.7
Th	11.6	12.1	82.7	41.3	31.0	37.5
U	4.0	1.3	2.2	2.7	1.3	2.2
V	94.6	64.8	24.4	28.8	18.0	14.0
W	0.7	0.4	1d	1.7	0.7	0.5
Y	29.4	13.6	21.3	10.7	11.9	11.5
Zn	99	95	105	57	49	47
Zr	339	177	592	437	223	151
La	48.10	40.90	193.60	137.10	62.55	86.11
Ce	115.50	83.60	383.40	259.60	127.20	157.50
Pr	14.93	9.43	42.29	26.03	13.24	16.24
Nd	59.15	33.57	143.10	82.94	43.91	53.35
Sm	10.95	5.75	21.08	10.64	6.79	8.08
Eu	2.42	1.19	1.88	1.36	0.85	0.92
Gd	7.64	4.11	11.99	6.09	4.32	4.83
Tb	1.06	0.54	1.34	0.63	0.52	0.58
Dy	5.56	2.85	5.61	2.72	2.60	2.69
Ho	1.01	0.53	0.76	0.42	0.45	0.44
Er	2.65	1.30	1.98	1.10	1.15	1.10
Tm	0.40	0.17	0.23	0.14	0.15	0.14
Yb	2.53	1.11	1.37	0.93	1.01	0.93
Lu	0.37	0.17	0.19	0.16	0.16	0.14

me = microgranular enclave; ton = tonalite; trond = trondhjemite; hb gr = hornblende-biotite granite; bt gr = biotite granite; lgr = leucogranite.

The Central Cameroon Domain exposes the partially molten root of the Pan-African Central African Orogenic Belt