# Paleoproterozoic Synkinematic Magnesian High-K Magmatism from the Tamkoro-Bossangoa Massif, along the Bossangoa-Bossembele Shear Zone in North-Western Central African Republic

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**Abstract** The magnesian high-K calc-alkaline intrusive of the Tamkoro-Bossangoa Massif, North Western Central African Republic, were synkinematically emplaced in a sinistral strike-slip shear zone of Paleoproterozoic age. The rock sequences consist of orthogneisses with abundant coarse- to medium-grained quartz monzodiorite, quartz diorite and medium- to fine-grained biotite granite composition and cover a range of about 55 to 76 wt.-% SiO<sub>2</sub>. They display characteristics of shoshonitic and high-K calc-alkaline series. Quartz monzodiorite and quartz diorite are metaluminous, whereas granite is moderately peraluminous ( $1 \le A/CNK \le 1.1$ ) and plot in the field of I-type granitoids. Major and trace element composition of the granitoids indicate that the source materials were derived from different crustal protoliths. Major and trace element composition are consistent with the magmatism which may have involved remelting of (1) a composite metagreywackes protolith in the upper crust and (2) amphibolitised high-K calc-alkaline basaltic andesites in the central domain of the NEFB (North Equatorial Fold Belt). SHRIMP zircon and titanite dating of granitic rocks gives a magmatic zircon and titanite age of 2069  $\pm$  9.6 Ma and 2063  $\pm$  28 Ma respectively, a metamorphic age of 500 Ma and 597 Ma. The plutonic rocks of Tamkoro-Bossangoa area resemble other Paleoproterozoic high-K calc-alkaline syntectonic plutons in western and central Cameroon. They also display strong similarities with high-K calc-alkaline plutons of eastern Nigeria and of the Borborema Province in NE Brazil.

**Keywords:** Metaluminous and Peraluminous granitoids, Orthogneiss, Magnesian series, I-type Granite, High-K calc-alkaline rocks, Crustal source, SHRIMP U-Pb dating, Central African Republic

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# **1. Introduction**

The Tamkoro-Bossangoa area, NW of Central African Republic (CAR), forms part of the North Equatorial Fold Belt (NEFB) that extends from Nigeria to the CAR through Cameroon and can be correlated with the Borborema Province of NE Brazil [1]. The NEFB is affected by the Central Cameroon Shear Zone (CCSZ), which is a major lineament of the Pan-African Orogen of Central Africa. This transcontinental shear zone is a major crustal discontinuity extending from north-eastern Brazil into CAR (Figure 1) and has been the focus of numerous investigations [2-9]. Deformation along the CCSZ is not homogeneous and is closely linked to granitoid intrusion events. In all these studies, the segment of the CCSZ in CAR has remained largely unstudied. Granitoids display great diversity in their origin, sources and evolution processes and thus can be used as indicators of geodynamic environments and, in some cases as tracers of geodynamic evolution [10,11]. Continental reconstructions for the Gondwana [e.g. [1,12,13,14]] show that the Pan-African/Brasiliano Cameroon, Nigeria and Borborema provinces occupied a central position in relation to the West Africa and Amazonian cratons, to the west, the Congo/São Francisco Craton, to the south, and the Saharan metacraton to the east [15]. In the lack of paleomagnetic data, understanding how and when this configuration was reached rely on geological and geochronological grounds. Knowledge of the tectonothermal history of the Proterozoic belts is thus

essential to evaluate possible correlations between adjacent (within individual provinces) and distant (transcontinental) units and, therefore, to provide insights into the dynamics of amalgamation of western Gondwana. The occurrence of deformed granitoids results from magma ascent and eruption, linked to ductile shear zones makes the Tamkoro-Bossangoa area a suitable site for studying the evolution of the CCSZ and its geodynamic significance in the NEFB in CAR. The relative timing of these magmatic events is still unclear in many parts of the CCSZ. The mapping of this area carried out during this study has revealed excellent exposures of the granitoids and has inspired this contribution.



Figure 1. Palinspatic reconstruction of Africa and NE Brazil (late-Precambrian) modified from [19]. ASZ: Adamawa shear zone (or Cameroon Central Shear Zone: CCSZ); SF: Sanaga fault; SL: São Luis Craton; Pa: Patos shear zone; Pe: Pernambuco shear zone; TBF: Tibati-Banyo- Foumban fault. BOF: Bétaré Oya Fault. The study area is marked by a rectangle

This paper provides new data on the geology and geochemistry of representative intrusions from the groups of granites and discusses the geological significance and petrogenesis of orogenic Paleoproterozoic, high-K calcalkaline magmas from the Northern-western part of the CAR in North-Equatorial Fold Belt; we also compare it with similar rock types in this region. The good exposure of apparently co-magmatic metaluminous, peraluminous and hyperpotassic rocks, spanning a continuous range of chemical compositions (with about 55 - 76 wt.-% SiO<sub>2</sub>), make the Tamkoro-Bossangoa Massif a key site to study, the formation of orogenic metaluminous and peraluminous, calc-alkaline magmas in this part of the NEFB. We report the first and new SHRIMP U-Pb in zircon and titanite geochronology.

## 2. Regional Geological Setting

The CAR has been divided in three major structural units [16-24], from south to north:

1. Southern unit represent a Northern part of Congo Craton and consists of (i) micaschists and quartzites of Archean and Paleoproterozoic age [25]; (ii) metabasites (amphibolites, pyroxenites of Mbomou) of Archean age (2900 Ma; [18]); (iii) charnockites series and gneisses similar to those of the Congo Craton in Cameroon [21], and (iv) Archean greenstones (komatiites), itabirites, greywacke, rhyodacitic tuffs and granitoids [26]. (v) The central part of this domain is occupied by an intermediate rock series (2100 Ma, [18]), which consists of quartzites, amphibolites and orthogneisses.

2. The intermediate domain consists of Archean gneisses, metabasites, granites and Paleoproterozoic metasedimentary rocks and migmatites. According to Rolin [24] these rocks are separated from the Neoproterozoic gneisses by a ductile shear zone.

3. The Northern part is composed of granulites, orthogneiss and granite of Neoproterozoic age  $(833 \pm 66 \text{ Ma [18]})$ . It corresponds to the western extension of the Pan-African fold belt in Cameroon. This domain is bordered in the south by a late Pan-African shear zone [27]. The Tamkoro-Bossangoa area (Figure 2) is affected in the north by a tectonic lineament more or less parallel to the Centrafricano-Tchadian border. This lineament

extends from Cameroon through the CAR to Sudan. The major lineament that crosses the Tamkoro-Bossangoa–Bossembele region from east to west is a mylonitic band that consists of pseudotachylites, blastomylonites and orthogneisses of the basement. This basement comprises also schist, micaschist, granulites and amphibolites [19]. The precise ages of rock units in the study area and the timing of movements along the Proterozoic structures in the CAR are unknown.



Figure 2. Geological map of the Tamkoro-Bossangoa massif

# **3.** Analytical Methods

Microprobe analyses were carried out at the University of Lausanne with a CAMEBAX SX50. Counting times were 15-30 s per element on peak and 5-30 s on background depending on concentration. The accelerating voltage was 15 kV for a beam current of 10-20 nA, depending on the sample analyzed. The beam was rastered over a surface of 10 x 8 microns for feldspars and 3 x 2 microns for hydrated minerals. Natural silicates were used as standards. After the petrographic characterization of the rock units, 24 representative samples were selected for whole rock chemical analysis. Samples were crushed and subsequently reduced to a very fine powder by grinding in a tungsten carbide ring mill. Major and trace element concentrations of whole-rock from 24 samples were analyzed by X-ray fluorescence spectrometry and LA-ICP-MS, at the University of Lausanne. Major elements (Si, Ti, Al, Fe, Mn, Mg, Ca, Na, K, P, Cr and Ni) were measured on fused lithium borate glass disks using a Philips PW2400 X-ray fluorescence spectrometer. Trace elements were measured from pressed powder pellets on the same XRF spectrometer (Nb, Zr, Y, Sr, U, Rb, Th, Pb, Ga, Ni, Cr, V, Ce, Ba and La), and by LA-ICP-MS on glass disks (Be, Sc, Ti, V, Cr, Ni, Cu, Zn, Y, Zr, Nb, Cs, La, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Hf, Ta, Pb, Th and U). Tests were made to assess the amount of trace element contamination, such as Ta and Nb, from the tungsten carbide mill. The samples analyses in this study are relatively rich in these elements, therefore contamination is considered negligible. Laser ablation measurements were made with a 193 nm Lambda Physik Excimer laser (Geolas 200M system) coupled to a Perkin-Elmer 6100 DRC ICP-MS. Laser settings were 27 kV with a 10 Hz repetition rate, yielding a fluorescence of about 12  $J/cm^2$  on the ablation site. Helium was used as carrier gas (1.1 l/mn) and NIST612 glass was used as the external standard, and Ca and Al as internal standards (on the basis of electron microprobe measurements on the ablation pit site). BCR2 basaltic glass was regularly used as monitor to check for reproducibility and accuracy of the system. Results were always within  $\pm$  10% range of the values reported by Witt-Eickschen et al. [28], while Rb, Cs, Y and especially Cr were sometimes of the  $\pm$  10% range of the USGS recommended values for BCR2. Analytical uncertainties are currently better than 1% for major elements and 5-10% for trace element concentrations higher and lower than 20%, respectively. Analytical precision for rare earth elements (REE) is estimated at 5% when concentrations are >10 times chondritic and at 10% when lower.

Samples of 1-2 kg were subjected by routine heavy mineral separation. Zircon and titanite were hand-picked, mounted in epoxy, and polished. Individual zircon grains were subjected to U-Pb isotopic analysis using the Sensitive High-Resolution Ion Microprobe (SHRIMP) at the Research School of Earth Sciences at the Australian National University, Canberra. Detailed SHRIMP analytical procedures have been reported by Compston et al. [29] and Williams and Claesson [30]. The technique focuses a primary beam of negative oxygen ions in vacuo onto the zircon and titanite surface from which a small area (25-30µm diameter) of sputtered positive secondary ions is extracted. Secondary ions, which include Zr, Th, U and Pb from the zircon, are passed through a curvilinear flight path in a strong magnetic field and then counted at a mass resolution of 6500 on a single collector using cyclic magnetic stepping. Isotopic ratios and inter-element fractionation are monitored by continuous reference to a standard Sri Lankan zircon (SL13), fragments of which are mounted with each sample. Progressive changes in the Pb/U ionic ratio during sputtering were corrected using an empirical quadratic relationship between  $Pb^+/U^+$  and  $UO^+/U^+$  determined for the standard zircon [31]. A radiogenic 206Pb/238U ratio of 0.0928 for the standard zircon, corresponding to an age of 572 Ma, is obtained through standard isotope dilution analysis. Initial Pb isotope compositions of the analyzed zircons are assumed to be similar to that of model-derived average crustal Pb of similar age according to Cumming and Richards [32]. The analytical precision of Pb isotope ratios is controlled by machine counting statistics whereas the precision of Pb/U ratios is affected by uncertainties in the recommended Steiger and Jäger [33] decay constants. Weighted mean <sup>207</sup>Pb/<sup>206</sup>Pb ages were obtained for zircons exhibiting an obvious clustering and indistinguishable <sup>207</sup>Pb/<sup>206</sup>Pb ages at a 95% confidence level. Individual analyses in the data tables and Concordia diagrams are presented at  $1\sigma$ . Errors associated with scatter within the cluster are obtained by standard statistical techniques. Dispersion within the cluster is attributed to modern Pb loss.

# 4. Results

## 4.1. Petrography

We use the P = K - (Na + Ca) vs. Q = Si/3 - (K+Na+2Ca/3) multi-cationic diagram (Figure 3) of Debon and Le Fort [34] for chemical classification of the different petrographic types. Orthogneiss plot in the quartz-monzodiorite, quartz-diorite and granite fields.



**Figure 3**. Position of the Tamkoro-Bossangoa granitoids in the Q = Si/3 - (K+Na+2Ca/3) vs P = K - (Na+Ca) multi-cationic diagram of Debon and LeFort [34]. (Mzdq = quartz monzodiorite; Dq = quartz-diorite; Gr = granite. Grey filled square = quartz monzodiorite; Open square = quartz diorite; Open circle = granite)

#### 4.1.1. Quartz Monzodiorite

The rock is grey-dark in colour, coarse grained, showing granoblastic or mylonitic microstructure (Figure 4a and Figure 4b). The samples are rich in ferromagnesian minerals, and the size of the grains vary from 1 cm to 8 cm and composed of quartz (2-8 vol.-%), plagioclase (20-30 vol.-%), K-feldspar (10-20 vol.-%), biotite (15-20 vol.-%), amphibole (30-45 vol.-%). Accessory phases are titanite ( $\leq$  3 vol.-%), allanite ( $\leq$ 1 vol.-%) and zircon ( $\leq$ 1 vol.-%). Quartz forms elongated polycrystalline ribbons ( $\leq$ 10 mm in the length). Perthitic K-feldspar ( $Or_{95-97}$ ) exhibits sigmoid (10 x 15 mm) or almond shape (35 x 20 mm), shows perthitic exsolutions of albite and also often show extensive development of myrmekite at the grain peripheries. The crystals contain small inclusions of opaque, apatite, biotite flakes or quartz grains. Plagioclase (An<sub>20-25</sub>) occurs as almond shape crystals that may be aligned sub parallel to the schistosity and may show undulatory extinction, or sigmoid shape preferentially oriented and show sinistral asymmetric (Figure 4c) or deformational twinning. Some crystals are locally sheared and have microfractures filled by biotite flakes and quartz grains. Large crystals are kinked. All are rimmed by quartz aggregates. Biotite ( $X_{Mg} = 0.50-0.56$ ) occurs as flakes of various dimensions that may be clustered, most of which derive from destabilization of amphibole. Amphibole is a green hornblende (ferroedenite) with almond shape (Figure 4d). Amphibole contains small

euhedral inclusions of biotite, titanite, apatite, zircon and ferriferous oxides.

#### 4.1.2. Quartz-Diorite

The Quartz-diorite (Figure 4e) is dark grey mediumgrained rocks with mylonitic microstructure (Figure 4f). They are composed of quartz ( $\leq 5$  vol.-%), K-feldspar (15-20 vol.-%), plagioclase (25-30 vol.-%; An<sub>30-31</sub>), biotite  $(30-35 \text{ vol.-\%}; X_{Mg} = 0.62)$ , amphiboles (20-35 vol.-%)and titaniferous oxide ( $\leq 3$  vol.-%); accessory minerals including titanite, allanite, zircon and apatite. Quartz forms elongated polycrystalline ribbons with undulatory extinction. K-feldspar (Or<sub>93-95</sub>) shows perthitic exsolutions of albite and inclusions of hornblendes. The crystals have sigmoid or almond shape (5 to 2 mm long axis). Some sections are fractured and filled by quartz grains and titaniferous oxide. Plagioclase occurs as almond shape crystals (3 x 2 mm to 2 x 5 mm. Some crystals display exsolutions of quartz (myrmekite) and others are zoned. Inclusions of apatite, zircon, biotite, opaque and titanite occur frequently in plagioclase. Biotite occurs as flakes of various dimensions that may be clustered, most of which have corroded margins, or forms euhedral inclusions in feldspars. Amphibole is a green hornblende with anhedral, or sigmoid shape Amphibole contains small euhedral inclusions of titanite, opaque and zircon.



Figure 4. Field occurrence and photomicrographs of the Tamkoro-Bossangoa granitoids. **a**: Field photograph of quartz monzodiorite; **b**: Mylonitic microstructure (quartz monzodiorite); **c**: Almond shape Kfeldspar megacrystal in quartz monzodiorite; **d**: Almond shape amphibole in quartz monzodiorite. **f**. Field photograph of quartz diorite; **f**: Mylonitic microstructure of quartz diorite; **g**: Field photograph of granite; **h**: Sheared K-feldspar crystals showing sinistral shear movement in granite

## 4.1.3. Granite

The granite is medium- to fine-grained rocks and display mylonitic microstructure (Figure 4g and Figure 4h). They are composed of quartz (20-30 vol.-%), K-feldspar (15-20 vol.-%), plagioclase (30-40 vol.-%), biotite (5-10 vol.-%); accessory minerals including titanite, zircon and apatite. K-feldspar shows perthitic exsolutions of albite. Some crystals are almond shape; more rarely rounded and contain small inclusions of biotite flakes, euhedral allanite. Plagioclase occurs as elongated, subhedral or rounded crystals that may be orientated and may show undulatory extinction. Biotite occurs as flakes of various dimensions, most of which have corroded margins, or forms euhedral inclusions in feldspars.

## 4.2. Geochemistry

#### 4.2.1 Major Elements



Figure 5. Harker diagrams of selected major elements. Symbols as in Figure 3

Major element concentrations of the Tamkoro-Bossangoa rocks are presented in Table 1. The rocks are silica-rich (with a total range of 55.75 - 75.65 wt. -% SiO<sub>2</sub>). In major element variation diagrams (Figure 5), the three rock types form well defined clusters and, taken together define more or less well-defined trends, where Al<sub>2</sub>O<sub>3</sub>, CaO, Fe<sub>2</sub>O<sub>3</sub><sup>tot</sup>, MgO, Na<sub>2</sub>O, TiO<sub>2</sub> and P<sub>2</sub>O<sub>5</sub> concentrations decrease monotonously with increasing amount of SiO<sub>2</sub>, whereas K<sub>2</sub>O increase with increasing of the SiO<sub>2</sub> content. The total alkali concentrations are uniform within each rock unit, i.e., 7.10 - 7.23 wt. -% in quartz monzodiorite, 5.81 - 6.0 wt. -% in quartz diorite and 8.24 - 9.44 wt.-% in granite. The granitoids are K-rich

and display characteristics of shoshonite to high-K calcalkaline series (Figure 6). High alkalis contents relative to CaO are characteristic of calc-alkalic to alkalic cordilleran granitoids according to the classification of Frost et al. [35]. When using the Al saturation index A/CNK = molar(Al<sub>2</sub>O<sub>3</sub>/ (CaO+Na<sub>2</sub>O+K<sub>2</sub>O), the quartz monzodiorite and quartz diorite are metaluminous, whereas granite is moderately peraluminous, and all conform to I-type (Figure 7) granitoids [36]. To discriminate between ferriferous granitoids and granitoids, we use the classification of Frost et al. [35], nearly all the granitoids of the Tamkoro-Bossangoa Massif plot in the magnesian field (Figure 8). These granitoids are similar to the other granites in the central domain of NEFB in Cameroon [e.g. [8,37-42]]. These granitoids are also geochemically similar to those from the Eastern Nigeria [43,44], and Borborema Province, NE Brazil [45]: all the rocks are metaluminous to weakly peraluminous (Figure 7b), high-K calc-alkaline and shoshonitic type (Figure 6b), and they are enriched in most incompatible elements (especially for K, Rb, Ba).



Figure 6. (a)  $SiO_2$  vs.  $K_2O$  diagram showing high-K calc-alkaline affinity of the Tamkoro-Bossangoa rocks. (b)  $SiO_2$  vs.  $K_2O$  diagram for the comparison between Tamkoro-Bossangoa, eastern Nigeria and NE Brazil granitoids. Symbols as in Figure 3

 Table 1. Representative chemical analyses of Tamkoro-Bossangoa plutonic rocks (wt. %)

Rock type		-		-	Quartz Mo	onzodiorite	-			
Samples	TAM1a	TAM1b	TAM1d	TAM2	TAM3	TAM4	TAM5	TAM6	TAM7	TAM8
wt-%										
SiO <sub>2</sub>	59.66	59.72	59.70	59.79	59.90	59.68	59.75	58.98	59.51	59.65
TiO <sub>2</sub>	1.08	1.07	1.07	1.21	1.21	1.18	1.12	1.14	1.15	1.10
$Al_2O_3$	16.85	16.91	16.83	16.74	16.95	16.58	16.90	16.67	16.93	16.70
Fe <sub>2</sub> O <sub>3</sub>	6.99	7.00	7.03	6.75	7.05	6.90	6.95	7.01	6.87	6.83
MnO	0.16	0.16	0.16	0.13	0.13	0.11	0.11	0.13	0.15	0.10
MgO	2.24	2.26	2.25	2.33	2.20	2.35	2.20	2.28	2.31	2.15
CaO	4.43	4.40	4.41	4.28	4.32	4.50	4.47	4.55	4.30	4.33
Na <sub>2</sub> O	3.65	3.67	3.64	3.64	3.61	3.58	3.55	3.59	3.61	3.65
K <sub>2</sub> O	3.47	3.53	3.51	3.59	3.58	3.57	3.55	3.60	3.50	3.45
$P_2O_5$	0.41	0.40	0.40	0.40	0.39	0.35	0.49	0.37	0.40	0.48
LOI	1.22	1.22	1.22	1.32	1.15	1.01	0.99	1.33	1.21	1.18
Sum	100.14	100.33	100.22	100.18	100.49	99.81	100.08	99.65	99.94	99.62
ppm										
Ba	729.0	716.0	789.3	736.0	783.1	980.0	850.0	705.0	720.0	750.0
Be	5.0	10.8	4.6	4.1	5.1	4.8	5.4	6.5	7.8	8.1
Co	225.0	43.6	36.0	36.2	42.7	39.0	51.0	48.0	41.0	44.0
Cr	2485.0	104.3	164.6	149.7	182.5	125.0	138.0	155.0	167.0	172.0
Cs	792.5	1557.9	467.2	876.6	926.3	564.0	798.0	813.0	821.0	800.0
Mo	0.5	15.1	2.8	0.4	0.5	0.4	0.5	0.4	0.5	0.6
Nb	26.3	3.8	4.5	5.5	11.0	17.0	15.0	21.0	23.0	25.0
Ni	1267.3	52.5	59.2	54.3	67.6	79.0	81.0	99.0	101.0	112.0
Rb	608.5	618.7	706.5	717.2	708.6	700.0	730.0	625.0	605.0	640.0
Sc	174.1	92.8	41.4	48.6	55.2	54.0	49.0	51.0	44.0	48.0
Sr	200	155	149	123	125	160	151	150	130	110
V	1024.6	345.7	331.7	316.8	377.9	380.0	398.0	326.0	355.0	361.0
Ý	1801	699	281	416	524	551	487	496	398	650
Zn	13.3	72.4	20.4	76.4	76.9	83.0	70.0	75.0	81.0	78.0
Zr	426.8	284.0	154.9	235.0	232.6	298.0	255.0	221.0	170.0	187.0
La	221.638	461.448	133.587	214.845	201.645	137.123	201.123	152.346	141.135	138.622
Ce	21.197	54.571	15.545	15.916	14.778	17.321	19.111	20.234	18.432	17.235
Pr	75.340	205.484	61.765	67.979	70.644	75.112	72.234	67.123	64.432	63.234
Nd	22.953	37.238	12.130	27.000	27.786	24.123	36.543	31.342	33.333	29.123
Sm	4.323	7.333	3.052	4.453	3.423	6.123	5.810	5.456	4.123	3.812
Eu	30.288	31.726	9.605	29.553	29.944	30.450	29.512	30.843	31.111	30.000
Gd	5.010	4.231	1.456	4.744	3.971	3.898	3.457	5.065	4.765	4.354
Tb	36.008	25.409	8.077	33.860	34,118	26.111	28.235	31.223	33.432	35.111
Dv	6.974	5.058	1.618	4.752	3.774	6.021	5.877	6.554	6.222	3.543
Ho	20.090	13.475	4.649	11.865	12.929	6.432	7.432	8.432	11.877	15.321
Er	2.986	1.885	0.640	1.267	1.697	2.432	2.123	1.632	1.412	2.021
Tm	19.472	13,923	4.429	16.897	15,729	14.457	15.123	17.123	17.346	16.781
Yb	2.779	2.212	0.715	2.223	2.430	2.457	2.568	2.679	2.499	2.123
Lu	45.380	17.764	7.091	17.189	18.226	16.235	19.235	21.123	20.432	16.123
Hf	0.855	5.636	1.410	1.156	1.360	1.568	2.457	2.346	1.321	1.111
Та	2.007	1.612	1.562	1.513	1.236	1.321	1.346	1.811	1.453	1.911
Pb	9.281	65.323	17.954	13.158	13.730	16.432	14.658	19.123	16.001	20.011
Th	3.113	11.832	7.369	5.214	2.312	4.123	5.235	8.235	6.346	6.123
U	40.200	40.433	40.200	40.200	40.200	40.765	40.897	41.123	39.467	37.010
(La/Yb)N	50.10	165.23	140.81	114.46	80.22	38.06	63.93	63.00	67.45	46.29
(Ce/Sm)N	1.18	1.80	1.23	0.86	1.04	0.68	0.79	0.90	1.08	1.09
(Gd/Yb)N	1.36	1.81	1.84	3.03	1.89	1.30	1.32	2.51	2.73	1.74
Eu/Eu*	19.90	17.41	13.93	19.66	24.83	19.06	20.13	17.94	21.46	22.51

Table 1 (Continued)

Rock type				Quartz diorite			
Samples	bgna1A	bgna1B	bgna1C	bgna2	bgna3	bgna4	bgna5
wt- %							
$SiO_2$	55.97	56.48	56.21	55.81	55.93	56.45	55.75
TiO <sub>2</sub>	1.26	1.26	1.26	1.23	1.21	1.33	1.38
$Al_2O_3$	16.44	16.53	16.49	16.61	16.55	16.41	16.35
$Fe_2O_3$	7.97	7.94	7.97	7.91	7.88	7.81	7.85
MnO	0.14	0.15	0.14	0.17	0.16	0.18	0.21
MgO	3.89	3.87	3.88	4.01	3.81	3.85	3.91
CaO	6.96	6.89	6.92	7.01	6.85	6.98	7.05
Na <sub>2</sub> O	3.98	3.96	3.98	4.01	4.05	3.90	3.87
K <sub>2</sub> O	1.89	1.91	1.88	1.85	1.95	1.91	1.98
$P_2O_5$	0.34	0.33	0.34	0.36	0.35	0.29	0.39
LOI	0.77	0.82	0.84	0.75	0.78	0.81	0.84
Sum	99.60	100.13	99.90	99.72	99.52	99.92	99.58
ppm							
Ba	605.4	715.1	577.5	585.0	598.0	601.0	590
Be	9.5	3.3	1.2	4.1	3.5	2.9	3.1
Co	42.4	58.6	114.9	87.0	78.0	65.0	61
Cr	105.1	1415.7	1268.9	1250.0	1261.0	1310.0	1385.0
Cs	1472.8	1.2	0.1	5.0	5.0	4.0	4
Mo	14.2	0.5	0.6	5.0	5.0	8.0	6.0

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Nb	35	11.0	8.0	65	4.2	7.0	7
Ni	55.9	402.1	1109.8	521.0	554.0	674.0	765.0
Rh	596.5	532.4	406.2	460.0	490.0	560.0	480
Sc	93.5	35.8	37.5	38.0	44.0	45.0	51.0
Sr	157	187	153	163.0	189.0	176.0	165
V	336.1	241.1	321.4	331.0	256.0	287.0	301.0
Ý	736	28	18	45.0	52.0	67.0	78.0
Zn	74.0	225.6	67.5	87.0	99.0	156.0	123.0
Zr	250.7	205.3	157.2	235.0	201.0	189.0	165
La	434.496	454.079	413.948	419.123	433.346	451.123	428.235
Ce	53.016	44.363	40.760	48.346	50.123	51.235	43.235
Pr	205.586	192.243	195.641	194.346	198.235	201.123	203.235
Nd	37.373	38.619	25.044	28.235	31.123	35.346	37.789
Sm	7.513	8.350	6.722	8.123	7.790	7.123	6.901
Eu	31.530	31.028	31.356	30.991	32.012	31.012	31.579
Gd	4.343	5.558	4.710	5.102	4.879	4.457	4.543
Tb	26.256	21.071	26.602	23.123	25.235	24.333	26.112
Dy	5.122	5.719	3.730	5.468	5.001	4.789	3.890
Ho	14.498	11.959	11.674	12.512	12.812	13.843	14.111
Er	2.085	2.438	1.664	2.326	2.235	1.946	1.900
Tm	14.272	13.319	12.229	14.213	14.001	12.512	12.835
Yb	2.310	2.124	1.891	1.912	1.801	2.011	2.221
Lu	18.468	17.293	18.215	17.511	16.123	16.432	17.023
Hf	5.987	6.006	4.958	5.023	5.432	5.832	5.901
Та	1.345	1.453	1.477	1.457	1.346	1.432	1.346
Pb	68.542	64.169	62.243	63.235	65.432	66.012	66.457
Th	12.129	12.385	11.002	11.988	12.011	11.846	11.457
U	40.200	40.582	40.167	39.453	39.678	39.898	40.168
(La/Yb)N	140.64	125.72	167.95	121.64	130.90	156.51	152.12
(Ce/Sm)N	1.70	1.28	1.46	1.44	1.55	1.74	1.51
(Gd/Yb)N	1.68	1.84	2.29	1.77	1.76	1.85	1.93
Eu/Eu*	16.87	13.92	17.04	14.72	15.87	16.83	17.24

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Samples         bgna2         bgna2A         bgna2B         bgna2-1         bgnaA2C         bgna2B2         bgna2-3           wt-%
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Zn         1.9         2.6         2.3         5.0         4.0         3.0         2.3           Zr         25.7         22.4         27.9         23.0         25.0         28.0         21.0           La         7.425         9.579         8.987         8.489         8.890         8.099         8.690
Zr         25.7         22.4         27.9         23.0         25.0         28.0         21.0           La         7.425         9.579         8.987         8.489         8.890         8.099         8.690
La 7.425 9.579 8.987 8.489 8.890 8.099 8.690
Le 0.565 1.180 0.704 0.912 0.891 0.767 0.679
Pr 1.710 2.810 2.394 1.891 2.012 2.346 2.679
Nd 0.340 0.463 0.481 0.412 0.446 0.346 0.468
Sm 0.197 0.500 0.780 0.321 0.612 0.612 0.678
Eu 0.249 0.278 0.369 0.321 0.249 0.321 0.249
Gd 0.137 0.153 0.063 0.123 0.135 0.157 0.179
Tb 0.225 0.308 0.338 0.257 0.268 0.289 0.179
Dy 0.067 0.169 0.094 0.088 0.091 0.871 1.980
Ho 0.220 0.263 0.280 0.279 0.298 0.288 0.243
Er 0.030 0.149 0.089 0.099 0.079 0.070 0.057
Tm 0.226 0.436 0.354 0.212 0.246 0.268 0.279
Yb 0.049 0.118 0.133 0.079 0.068 0.057 0.035
Lu 0.534 1.246 1.330 0.789 0.891 0.987 1.099
Hf 0.148 0.239 0.184 0.199 0.168 0.068 0.059



Figure 7. Alumina index diagram (Molar  $Al_2O_3$ / (CaO + Na<sub>2</sub>O+K<sub>2</sub>O) vs  $Al_2O_3$ / (Na<sub>2</sub>O + K<sub>2</sub>O) for the Tamkoro-Bossangoa granites (a) and (b) comparison between Tamkoro-Bossangoa, eastern Nigeria and NE Brazil granitoids. Symbols as in Figure 3. Boundary between I- and S-type according to Chappell and White [36]



**Figure 8.** Position of the Tamkoro-Bossangoa granites in the SiO<sub>2</sub> vs. FeOt/(FeOt + MgO) diagram, axis units are wt%. Symbols as in Figure 3

#### 4.2.2. Trace Elements

Trace element concentrations of the Tamkoro-Bossangoa rocks are presented in Table 1. Selected elements are plotted against SiO<sub>2</sub> content in Figure 9. Ni, Sr concentrations decrease with decreasing SiO<sub>2</sub> content. Other concentrations are in general scattered on variation diagrams. Zr/Y ratios range between 0.01 and 8.05 (average 3.97) and higher than Nb/Y ratios (0.005-0.4) < 1. These values are similar to those observed in continental calc-alkaline igneous suites [46]. Chondrite-normalized rare earth element (REE) patterns of the Tamkoro-Bossangoa suite (Figure 10) resemble each other, in general with LREE enrichment with Ce<sub>N</sub>/Sm<sub>N</sub> ratios of 0.68 - 1.8 and Gd<sub>N</sub>/Yb<sub>N</sub> ratios of 1-3, significant Positive anomalies (Eu/Eu\* = 14-25) in the Quartz Eu\* monzodiorite,  $Ce_N/Sm_N=1.28$ - 1.74 and  $Gd_N/Yb_N=1.68$  -2.29, with strong positive Eu\* anomalies (Eu/Eu\* = 14-17) in the quartz diorite and Ce<sub>N</sub>/Sm<sub>N</sub>=0.29- 0.69,

 $Gd_N/Yb_N=0.57$  -3.74, positive Eu\* anomalies (Eu/Eu\* = 3.1-5.1) in the granite. This anomaly underlines the role of the plagioclase accumulation in the formation of these rocks.



Figure 9. Harker diagrams of selected trace elements. Symbols as in Figure 3



Figure 10. Chondrite-normalized REE and multi-element patterns for the Tamkoro-Bossangoa granites

The multi-element spectra (Figure 10) of all these rocks show a distinctive depletion in K, Nb, Sr and Zr relative to other trace elements (characteristic of calc-alkaline granites of crustal origin [47], and enriched in LILE (large ion lithophile elements) and display negative anomalies in K, Nb, Sr, Zr, Y, Th and Ti. These rocks display less pronounced negative anomalies in Sr and Ti, and lower Y and Yb values resulting in more "fractionated" trace element distribution patterns, characteristic of calcalkaline arc granitoids.

## 4.3. Geochronology

#### 4.3.1. Zircon Morphology and Internal Structure

Zircon grains from the quartz monzodiorite have distinct morphologies and internal structures. In sample TAM 1b, most grains are brownish and elongated with the original euhedral to subhedral shape clear visible despite of rounded terminations. Oscillatory zoning, typical of magmatic growth, is common (Figure 11). In CL images grain show thick oscillatory growth- and sector zonation and thin external zone due to a metamorphic growth type [48]. The Th/U ratios vary from 0.84-1.10 in the core to 0.33-0.78 in the zonation sector and 0.40 in the external zone (Table 2).

Table 2. Analytical data for zircons, from the selected sample, from Tamkoro-Bossangoa plutonic rocks

Grain.Spot	% <sup>206</sup> Pb <sub>c</sub>	Ppm U	ppm Th	<sup>232</sup> Th / <sup>238</sup> U	Ppm <sup>206</sup> Pb*	(1) <sup>206</sup> Pb/	<sup>238</sup> UAge	(1) <sup>207</sup> Pb/ <sup>21</sup>	<sup>06</sup> PbAge	%Dis-cor- dant	(1) <sup>207</sup> Pb <sup>*/206</sup> P	b <sup>*</sup> ±%	(1) <sup>207</sup> Pb*/ <sup>23</sup>	<sup>35</sup> U ±%	(1) <sup>206</sup> Pb <sup>*</sup> / <sup>23</sup>	<sup>8</sup> U ±%	erreur
1.1	0.15	467	224	0.49	75,7	1113	±11	1773	±23	37	0,1084	1,3	2,816	1,7	0.188	1,1	0.642
1.2	0.16	144	117	0.84	40,8	1834	±19	2118	±24	13	0,1315	1,4	5,97	1,9	0.329	1,2	0.656
2.1	0.00	304	97	0.33	93,5	1974	±19	2060,4	$\pm$ 8,9	4	0,12725	0,51	6,285	1,2	0.358	1,1	0.910
3.1	0.00	265	96	0.37	83,7	2017	±19	2068	$\pm 7,8$	2	0,12781	0,44	6,473	1,2	0.367	1,1	0.931
3.2	0.06	225	79	0.36	68	1942	±19	2036,1	$\pm 7,8$	5	0,12552	0,44	6,086	1,2	0.352	1,1	0.930
4.1	0.24	406	206	0.53	68,4	1154	±11	1880	±13	39	0,11503	0,73	3,108	1,3	0.196	1,1	0.829
5.1	0.07	246	125	0.53	73,7	1927	±23	2073,4	$\pm$ 8,8	7	0,1282	0,5	6,157	1,5	0.348	1,4	0.940
5.2	0.15	196	122	0.64	56,1	1848	$\pm 18$	2032,5	$\pm 9,5$	9	0,12526	0,53	5,735	1,3	0.332	1,1	0.904
6.2	1.81	439	270	0.64	55,3	867,2	$\pm 8,7$	1516	±33	43	0,0944	1,7	1,874	2	0.144	1,1	0.525
7.1	0.00	158	206	1.35	50,7	2050	±23	2055,3	$\pm 10$	0	0,12689	0,57	6,551	1,4	0.374	1,3	0.919
7.2	0.00	215	98	0.47	66,9	1993	±23	2066,7	±9	4	0,12771	0.51	6,378	1,4	0.362	1,4	0.936
7.3	0.24	296	324	1.13	66,5	1496	±15	1940	$\pm 11$	23	0,11891	0,62	4,284	1,3	0.261	1,1	0.868
8.1	0.03	489	188	0.40	85,9	1198	±14	1781,5	$\pm 9,1$	33	0,10892	0,5	3,067	1,3	0.204	1,3	0.929
8.2	0.02	385	412	1.10	94,2	1616	±16	1990	±12	19	0,12228	0,67	4,802	1,3	0.285	1,1	0.852
8.3	0.04	397	149	0.39	84,9	1431	±14	1892,7	$\pm 8$	24	0,11582	0,44	3,97	1,2	0.249	1,1	0.924
9.1	0.14	404	312	0.80	90,1	1487	±14	1961	±13	24	0,12035	0,75	4,304	1,3	0.259	1,1	0.825
10.1		311	101	0.34	97,4	2005	±19	2063,7	±7,4	3	0,12749	0,42	6,415	1,2	0.365	1,1	0.936
11.1	0.04	366	276	0.78	111	1952	$\pm 18$	2039,7	$\pm 7,1$	4	0,12577	0,4	6,134	1,2	0.354	1,1	0.938
12.2	3.56	515	269	0.54	61,6	813.1	$\pm 8.4$	1409	±56	42	0,0892	2,9	1,654	3,1	0.134	1,1	0.355
13.1	0.08	331	166	0.52	89,2	1756	±17	2006,9	$\pm$ 8,8	12	0,12347	0,5	5,331	1,2	0.313	1,1	0.915
14.1	0.07	300	81	0.28	95,6	2030	±19	2036	$\pm 7,8$	0	0,12551	0,44	6,405	1,2	0.370	1,1	0.930
15.1	0.00	435	205	0.49	98,1	1502	±15	1927,9	$\pm 7,5$	22	0,11811	0,42	4,274	1,2	0.262	1,1	0.933
16.1	0.22	405	270	0.69	94,5	1545	±15	2002,6	$\pm 9,4$	23	0,12317	0,53	4,598	1,2	0.271	1,1	0.898
17.1	0.03	241	114	0.49	72,1	1925	±19	2067,3	$\pm 8,7$	7	0,12776	0,49	6,131	1,2	0.348	1,1	0.918
18.1	0.27	273	81	0.31	79,6	1880	±19	2135	$\pm 11$	12	0,13274	0,65	6,197	1,3	0.339	1,1	0.869
19.1	0.04	352	246	0.72	82,6	1556	±15	1989,3	$\pm 8,6$	22	0,12225	0,48	4,603	1,2	0.273	1,1	0.916
20.1		328	447	1.41	102	1990	±19	2050,3	$\pm 8,6$	3	0,12653	0,49	6,309	1,2	0.362	1,1	0.918
21.1	0.09	394	124	0.32	85,9	1456	±14	1956,9	$\pm 9,5$	26	0,12004	0,53	4,195	1,2	0.253	1,1	0.898
22.1	0.06	332	142	0.44	81,1	1614	±16	1996	$\pm 11$	19	0,1227	0,6	4,813	1,3	0.285	1,1	0.877
22.2	0.00	270	86	0.33	79,3	1898	±19	2039,7	$\pm 9,4$	7	0,12577	0,53	5,937	1,2	0.342	1,1	0.905
23.1	0.02	352	196	0.58	93,1	1729	±17	2012.7	$\pm 8$	14	0,12387	0,45	5,254	1,2	0.308	1,1	0.925
23.2	0.30	314	298	0.98	82,4	1713	±20	2000	±17	14	0,123	0,95	5,162	1,6	0.304	1,3	0.815
24.1	0.00	101	75	0.77	31,5	2005	±22	2054	±11	2	0,12681	0,62	6,38	1,4	0.365	1,3	0.903
24.1b	0.08	76	79	1.07	21,9	1875	±20	2050	±12	9	0,12653	0,69	5,889	1,4	0.338	1,2	0.874
25.1	0.28	271	324	1.24	86,2	2027	±20	2038	±19	1	0,1257	1	6,4	1,5	0.369	1,1	0.734
25.2	0.03	263	333	1.31	86,2	2080	±20	2057,7	$\pm 6,9$	-1	0,12706	0,39	6,672	1,2	0.381	1,1	0.943
26.1	0.19	223	119	0.55	62,6	1816	±18	2025,9	$\pm 9,3$	10	0,1248	0,52	5,599	1,2	0.325	1,1	0.906

Errors are 1-sigma; Pbc and Pb\* indicate the common and radiogenic portions, respectively.

Error in Standard calibration was 0.31% (not included in above errors but required when comparing data from different mounts). (1) Common Pb corrected using measured <sup>204</sup>Pb.



**Figure 11.** Cathodoluminescence (CL) images of typical zircons from the quartz monzodiorite (Tam 1b). Note the thick oscillatory growth and sector zonation (typical of magmatic growth) and thin external zone due to metamorphic growth.

#### 4.3.2. U-Pb Results

On the Concordia diagram (Figure 12a) zircon fraction Tam 1b define a discordia line with upper and lower intercepts of  $2069 \pm 9.6$  Ma and  $500 \pm 40$  Ma (MSWD= 4.6). On the basis of the zircon morphology, structure and Th/U ratios, this age is interpreted as the magmatic age for the Tamkoro-Bossangoa massif. The remaining analyses (points 1.2 and 18.1) were of zircon have inherited core (as shown in CL images) giving a minimum  $^{207}$ Pb/ $^{206}$ Pb age of 2012 Ma (Figure 12a). The lower intercept corresponds to a Neoproterozoic tectono-metamorphic history.

An important quantity of the good quality of dark brown titanite has been collected to heavy minerals separation. This titanite has high U contents that allow making U-Pb analysis. Six points were analyzed on titanite from sample Tam1b (Table 3). Titanite fraction define a Discordia line (Figure 12b) with upper and lower intercept of  $2063 \pm 28$  Ma and 597 Ma (MSWD = 0.25) respectively. This result is quite similar to those obtained in zircons.



Figure 12. Concordia diagram showing all SHRIMP data points for zircon (a) and titanite (b) from the quartz monzodiorite (sample Tam 1b)

 Table 3. Analytical data for titanite, from the selected sample, from Tamkoro-Bossangoa plutonic rocks

Grain Spot	% <sup>206</sup> Pb <sub>c</sub>	ppm U	ppm Th	<sup>232</sup> Th/ <sup>238</sup> U	ppm <sup>206</sup> Pb*	<sup>206</sup> Pb/ <sup>238</sup> U	<sup>207</sup> Pb/ <sup>206</sup> Pb	%discordant	<sup>207</sup> Pb/ <sup>206</sup> Pb	<sup>207</sup> Pb/ <sup>235</sup> U	206Pb/238U	Erreur
1,1	1,24	137	157	1,18	39,7	1852±30	2001±22	7	0,1231±1,2	5,65±2,3	0,3329±1,9	0,835
2,1	2,45	226	1057	4,82	5,9	1668±24	1987±69	16	0,1221±3,9	4,97±4,2	0,2953±1,6	0,386
2,2	1,24	264	540	2,12	75,4	1832±24	2028±25	10	0,125±1,4	$5,66\pm 2,1$	0,3287±1,5	0,729
3,1	0,89	113	789	7,25	36,8	2064±36	2062±18	0	0,1273±1	6,63±2,3	0,3774±2	0,889
4,1	1,38	153	528	3,57	46,1	1916±30	2036±36	6	0,1255±2	5,99±2,7	0,3461±1,8	0,672
5,1	0,40	269	437	1,68	84,1	1995±26	2051,5±9	3	$0,12662\pm0,51$	6,332±1,6	0,3627±1,5	0,946

# 5. Discussion

## 5.1. Conditions of Emplacement

We applied Zr saturation geothermometer [49,50] to Tamkoro-Bossangoa granitoids to estimate the minimum temperatures of the melts (assuming that there is no residual zircon inherited from the source). The calculated temperatures (Table 4) range between 756 - 846°C for the quartz monzodiorite, 722 - 758°C for the quartz diorite, 638 - 658°C for the granite. These temperatures are consistent with those of crustal granites [40,50,51].

# 5.2. Source of the Tamkoro-Bossangoa Magmas

The nature of the igneous source can be constrained using the geochemical signatures of the plutonic rocks. The investigated plutonic rocks exhibit petrographical and chemical compositions characteristic of high-K to shoshonitic I-type granitoids [52] derived from partial melting of igneous rocks. The geochemical compositions of Tamkoro-Bossangoa granitoids as shown on Harker's diagrams did not indicate continuous compositional variation from one group to another, but little internal compositional variation and overlap between some groups. This suggests that the compositional variability of these granitoids does not appear to be generated mainly by fractionation processes, but testify an evolution by accumulation as main process in the Tamkoro-Bossangoa granitoids. The High-K calc alkaline magmatism of these rocks is typical of those of collisional to post collisional

orogenic domain [e.g. [6,8,20,38,40,53,54]], and also indicate an active margin environment.

Table 4. Calculated temperatures using Zr saturation geothermometer of Harrison and Watson [49], and Watson and Harrison [50]

Samples	Zr (ppm)	T°.C
	Quartz monzodiorite	
TAM1a	426	846
TAM1b	284	808
TAM1d	155	756
TAM2	235	792
TAM3	232	792
TAM4	298	809
TAM5	255	799
TAM6	221	782
TAM7	170	766
TAM8	187	772
	Quartz diorite	
bgna1A	251	758
bgna1B	205	744
bgna1C	157	722
bgna2	235	753
bgna3	201	741
bgna4	189	736
bgna5	165	723
-	Granite	
bgna2	25.74	652
bgnaA2A	22.43	643
bgna2B	27.90	658
bgna2-1	23	640
bgnaA2C	25	649
bgna2B2	28	655
bgna2-3	21	638

High Ba/Sr (1.5 -6.8) and Ba/Rb (1 - 1.5) ratios are typical for granites of crustal origin (Harris and Inger, 1992). The enrichment of Ba (465-980ppm) relative to Sr (110-200ppm) and the high  $K_2O$  (1.85-6.33%) suggest a pelitic parent [55].

The strong positive Europium anomaly (Eu/Eu\*=2-22) underline the role of the plagioclase accumulation in the formation of the granitoids. In fact, the plagioclase accumulation contribute to enrich the magma on Europium during the differentiation, this create the positive anomaly in that element. The LREE high content is certainly due to the abundance of amphibole and accessories phases such as titanite, allanite and apatite. The HREE significant content (10 to 50 times Chondrite values) is due to a relative abundance of Zircon.

The REE and multi-elements patterns (Figure 10) suggest genetic processes involving garnet. The high contents of LREE in all rocks could be related either to the enrichment of their source materials in LREE, or to a low degree of partial melting of source protoliths with garnet and amphibole among the residual phases. However, their concentrations in HREE (more or less 10 times the Chondrite values) do not support the assumption of a source containing garnet. The spider diagrams characteristically display negative anomalies for Sr, Ba and Ti. These anomalies result either from the low content of these elements in the source, or their retention in the residue during partial melting. The geochemistry and mineralogy of the granitic rocks reflect not only the nature of the protoliths from which they were derived, but also the dynamic conditions under which magmas were formed, evolved and eventually solidified [56]. Compositional differences of melts produced by partial melting of different source rocks, such as amphibolites, tonalitic gneisses, metapelites and metagreywackes, under variable melting conditions can be visualised in terms of molar

CaO/(MgO + FeO<sub>total</sub>) vs. molar Al<sub>2</sub>O<sub>3</sub>/(MgO + FeO<sub>total</sub>) of Altherr et al. [57] (Figure 13). In that diagram, the samples plot in the field of partial melts from metagreywacke and metabasaltic sources. These source rocks are predominantly found in the low and upper part of the continental crust and we suggest that the source for Tamkoro-Bossangoa plutonic rocks the was a metagreywacke and a metabasalt. Such source protolith with significant proportions of metasedimentary rocks was indicated for the high-K calc-alkaline plutons of the Borborema province in the NE Brazil [45,58,59,60] and eastern Nigeria [43,61,62]. The high-K calc-alkaline to shoshonitic and metaluminous nature of the Tamkoro-Bossangoa plutonic rocks require a metaluminous and relatively K-rich source [63,64]. The differences observed in granites can be explained by differences in melting conditions and/or minor variation in source compositions. The low Rb/Sr and the enrichment of LREE of the rocks are probably inherited from the source. Thus, the magmatism of the Tamkoro-Bossangoa plutonic rocks may have involved remelting of a composite acid metagreywackes and metabasalt protoliths in the lower to upper crust. The large-scale melting of the source rocks could have been favoured by high heat flow during Paleoproterozoic orogenesis or underplating of mantlederived magmas into the crust.



Figure 13. Molar CaO/ (MgO + FeOt) vs  $Al_2O_3$ / (MgO + FeOt) for the Tamkoro-Bossangoa granites. Symbols as in Figure 3

The high contents of LREE in the rocks could be related either to the enrichment of their source materials in LREE, or to a low degree of partial melting of source protoliths. The spider diagrams characteristically display negative anomalies for Sr, Ti and Nb. These anomalies result either from the low content of these elements in the source, or their retention in the residue during partial melting. The geochemistry and mineralogy of the granitic rocks reflect not only the nature of the protoliths from which they were derived, but also the dynamic conditions under which magmas were formed, evolved and eventually solidified [56].

#### **5.3.** Thermo-Tectonic Evolution

#### 5.3.1. Crustal Evolution through Time

This work clearly reveals that two main thermotectonic events affected the study area, one in the Paleoproterozoic (Eburnean orogeny) and the other at the end of the Neoproterozoic (Pan-African orogeny). The age pattern of sample Tam1b allows placing tight constraints on the events associated with the Paleoproterozoic orogeny. The lack of inherited cores, as revealed by CL images, indicates that the age of  $2069 \pm 9.6$  Ma corresponds to the crystallization age of the orthogneiss protolith. All wholerock samples of orthogneiss display geochemical characteristics similar to calc-alkaline magmas, indicating generation in an active margin setting [54]. Considering this, the age reported here could correspond to juvenile crustal accretion. The younger age (500-597 Ma) found in sample Tam1b is associated with metamorphic features observed in the analyzed zircon grains and is interpreted as reflecting a stage of late to post-orogenic magmatism at Pan-African time. Although the importance of the Paleoproterozoic event in the study area is obvious, fieldwork [19,65], and the geochronological results from this study indicate that the dominant mesoscopic ductile fabric in Paleoproterozoic orthogneisses was produced during the Paleoproterozoic.

#### 5.3.3. Paleoproterozoic Orogeny

The two age groups in sample Tam1b are similar to those found from (1) the Cameroon Central domain of the NEFB, where recent analyzed by conventional methods of U-Pb data indicate magmatic crystallization at 2200-2050 Ma and high-grade metamorphism at 2150-2050 Ga [e.g. [66,67]]; (2) the Borborema Province in NE Brazil, where most Paleoproterozoic U-Pb ages are well documented [e.g. [2,68]]. Nevertheless, the existing data point out to an important period of crust generation at 2200-2000 Ma, followed by deformation and metamorphism, and then by intrusion of late- to post tectonic plutons.

This result associated with the recent geochronology work in Nigeria and Cameroon [44,67,69] also point out to the existence in Central Africa of an old continental crust (Archean and Paleoproterozoic) which are reworked during Neoproterozoic orogeny.

#### 5.4. Implications for Western Gondwana

The results of this study and the recent synthesis by Neves et al. [13] and Ferré et al. [44] on the geodynamic evolution of NE Brazil and Nigeria, respectively, are strongly indicate that these belts shared a common evolution throughout most of the Proterozoic. Common features include (1)extensive (ca. 2100Ma) Paleoproterozoic and dominance crust (2)of transcurent/transpressional deformation after 600 Ma. Destabilization of a preexisting continent formed at the end of the Eburnean/ Transamazonian orogeny (the Atlantica supercontinent of Rogers [70]) provides the simplest explanation to the above findings.

## 6. Conclusions

Considering the results presented in this paper, as well as the interpretation, the following conclusions can be drawn.

1. The Tamkoro-Bossangoa Massif comprises Paleoproterozoic magmatic rocks. The main rock units in

the massif are monzodiorite. All the granitoids have undergone the same deformation as the basement metamorphic rocks and both share the same structural patterns. Field relations, petrography and structural observations, point to the fact that these granites are syntectonic intrusive.

2. Plutonic rocks from the Tamkoro-Bossangoa area are metaluminous and slightly peraluminous and conform to I-type granitoids. They are high-K, calc-alkaline to shoshonitic syntectonic intrusions emplaced during the Paleoproterozoic event in Central Africa Republic, in the close spatial association with the Bossangoa-Bossembele Shear Zone. They also display negative anomalies in Sr, Nb and Ti, and lower Rb, Y and Yb values characteristic of high-K calc-alkaline series.

3. The data in this paper indicate that these three granitic rocks assemblage did not result from the simple differentiation of a common parental magma. The data also suggest that the Tamkoro-Bossangoa plutonic rocks were derived from different crustal protoliths. Major and trace element composition of the monzodiorite, quartz diorite and granites of the Tamkoro-Bossangoa Massif are consistent with the magmatism which may have involved remelting of (1) a composite metagreywackes protolith in the upper crust and (2) amphibolitised high-K calc-alkaline basaltic andesites in the central domain of the NEFB.

4. SHRIMP U-Pb dating on zircon and titanite clearly reveals that two main thermotectonic events affected the Tamkoro-Bossangoa area, one in the Paleoproterozoic (Eburnean orogeny) and the other at the end of the Neoproterozoic (Pan-African orogeny). These two events are similar to those found from Central domain in Cameroon and Borborema Province in NE Brazil. These data point out to an important period of crust generation at 2200–2000 Ma. Our result associated with the recent geochronology work in Nigeria and Cameroon also evidenced that Central Africa is an old continental crust (Archean and Paleoproterozoic) reworked during Neoproterozoic orogeny.

5. The plutonic rocks of Tamkoro-Bossangoa area are very similar to other Paleoproterozoic high-K calcalkaline syntectonic plutons from western and central east Cameroon in modal, major and trace element characteristics. Roughly similar syntectonic plutonism in relation with lithospheric-scale shear zone is also observed in the eastern Nigeria and the Borborema province of NE Brazil, especially close to the Damagaram and Pernambuco shear zone respectively.

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