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RESEARCH ARTICLE

SYNKINEMATIC FERRO-POTASSIC CAL-ALKALINE MAGMATISM FROM THE YORO-YANGBEN MASSIF, ALONG THE SOUTHERN PART OF CENTRAL DOMAIN OF CAMEROON PAN-AFRICAN FOLD BELT

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ABSTRACT

In this study we examine the geological significance and petrogenesis of orogenic Pan-African high-K calc-alkaline magmas from the Yoro-Yangben area in southern part of central domain of the Pan-African, North-Equatorial Fold Belt in Cameroon. The objective is to constrain the source and the geotectonic setting of these magmas and therefore to understanding the geodynamic environment of the Yoro-Yangben massif in the Bafia series. 21 samples were analyzed by XRF and ICP-MS. The rock sequences consist of orthogneisses with abundant granodiorite, granite biotite and quartz monzonite composition associated to amphibolite and covers a range of about 46 to 76 wt.-% SiO_2. Rocks are metaluminous and of I-type granitoids and characterized by variable LREE enrichment, moderate HREE fractionation with strong negative Eu anomalies. Trace element distribution patterns show that these rocks were derived from crustal protoliths. Sm-Nd and T_{DM} ages point a heterogeneous source and the ε_{Nd} values a major crustal component. The $^{87}Sr/^{86}Sr$ ratios indicate that the protolith had a short crustal history. Tectonic evolution is polyphase and monocyclic. Kinematic criteria (C-S fabrics, φ, δ, σ structures), magmatic and solid state deformation markers combine to the elongated shape of the plutons parallel to the Cameroon Central Shear Zone point to syntectonic (D_2) magma emplacement compatible with a ductile shear zone which controls the plutonic rocks emplacement. These results resemble other Neoproterozoic high-K calc-alkaline granites of Cameroon and Central Africa Republic and also display strong similarities with high-K calc-alkaline plutons of eastern Nigeria and the Borborema Province in NE Brazil.

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INTRODUCTION

Several work was carried out on various granitoid massive (Nguiessi and Vialette, 1994; Ganwa, 1998; Nzenti, 1998a; Tanko Njiosseu *et al.*, 2005; Nzenti, Tanko Njiosseu, and Nchare Nzina, 2007; Ganwa *et al.*, 2008; Njiekak *et al.*, 2008; Nchare Nzina *et al.*, 2010; Chebeu *et al.*, 2011; Nzenti *et al.*, 2011) in the Cameroonian central domain. Questionings remain in particular on the geochemical similarities and variations, the nature of the source and the evolution of the magmas at the origin of the granitoid. Brief in what the granitoid of the Cameroonian central domain are different to each other and different from the other granitoid of the same age? How are they in the models of geodynamic evolution of the Pan-African North Equatorial fold belt in Cameroon?

Can the study of the Yoro-Yangben massif with its particular and exceptional conditions of outcrop, to be used as models of study for Pan-African petrogenesis and tectonics? It is essential to examine the tectono-magmatic evolution of this massif before proposing possible models of emplacement. Gaps remain in the forefront of which detailed petrogenesis, the kinematics of the shear zone and mutual relations between these shear zones and the emplacement of the Pan African magmas. The massif of Yoro-Yangben to the SW of Bafia is precisely located in the shear zone and of this fact constitutes a key zone for the study and the comprehension of the relations between magmatism and deformation along Cameroon Central Shear Zone, their geodynamic significance in the Pan African North Equatorial Fold Belt in Cameroon and to make a comparative study with the establish characters of the Cameroonian central domain, Nigeria and of the NE Brazil.

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GEOLOGICAL SETTING

Regional geology

The Bafia series (Fig.1) is localized in central domain of the Pan-African North-equatorial fold belt in Cameroon; this field to which our zone of study belongs, corresponds to a NE-SW geographical area extending from the South of Bafia to the South of Poli. It is an intermediate domain constituting the link between the northern and southern parts of the fold belt. It is marked by multiple regional strike-slip faults, and it comprises many syntectonic plutons with calc-alkaline affinity and of Pan-African age, intruded in the strongly metamorphic host rocks formed by Archaean to Paleoproterozoic high grade gneisses and amphibolite (Nguiessi *et al.*, 1997; Nzenti, 1998b; Tagne-Kamga *et al.*, 1999; Tagne-Kamga, 2003; Tanko Njiosseu *et al.*, 2005; Njanko *et al.*, 2006; Nzenti *et al.*, 2006; Ganwa *et al.*, 2008; Njiekak *et al.*, 2008; Nono Ganno *et al.*, 2010; Kouankap *et al.*, 2010; Chebeu *et al.*, 2011; Nzenti *et al.*, 2011). Four main phases of deformation were evidenced in this area (Weecksteen, 1957; Nzenti *et al.*, 2011).

Local setting

The Yoro-Yangben region belongs to the Bafia series and it is located between Sanaga shear zone at the south, and Cameroonian central shear zone in the North (Fig. 1 and 2). The first recognition work of Weecksteen (1957) distinguishes two groups' rocks: (i) gneisses and quartzite, (ii) biotite and/or amphibole rich migmatite. Recent studies (Ganwa *et al.*, 2008; Tchakounté *et al.*, 2007; *Ngnotue* et al.*, 2012***)** in the Bafia series allowed to identify métasédiments (metashales and metagreywackes) and alkaline metavolcanites resulting from the melting of an old Archaean and Paleoproterozoïc crust (Ganwa *et al.*, 2008; Ganwa, 1998; *Ngnotue* et al.*, 2012;* Mvondo, 2009). The granitoids are mostly represented by the Pan-African orthogneisses (Ganwa, 1998). On the structural level, Weecksteen (1957) ascribe the tectonic history of the Bafia region to two phases of deformations; one is a ductile phase, represented by a syn-metamorphic folding of unknown age and a brittle phase, dominated by vertical movements. Following these first authors, Tchakounté *et al.* (2007), *Ngnotue* et al. *(2012)* evidences two phases of ductile

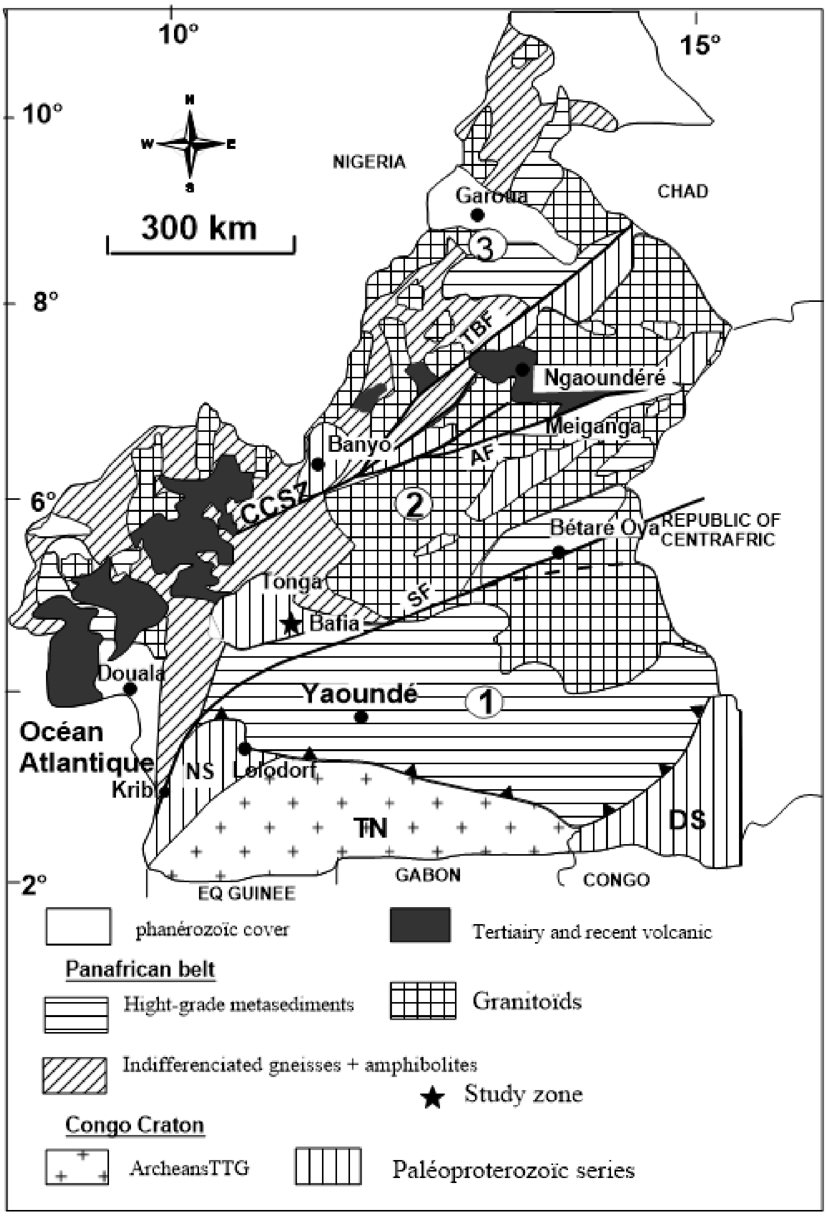

Figure 1. Geological map of Cameroon (Nzenti et al., 2011) showing the localization of the Yoro-Yangben area and the main lithotectonic units: (1) southern domain; (2) central domain; (3) northern domain; CCC: Cameroonian Central shear zone; FS: Sanaga Fault; FTB: Tibati-Banyo Fault; NT: Ntem Complex; SD: Dja Series; SN: Nyong Series; FA: Adamaoua Fault

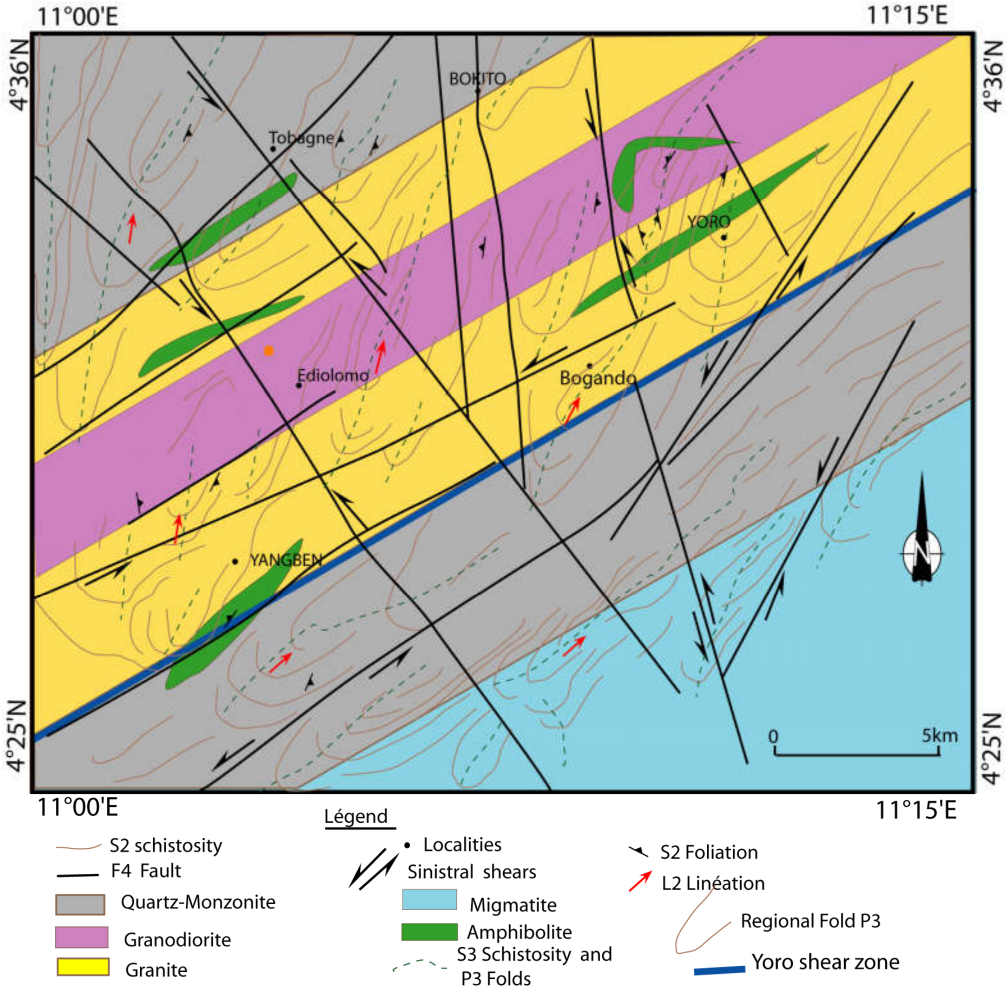

Figure 2. Geological map of the Yoro-Yangben massive

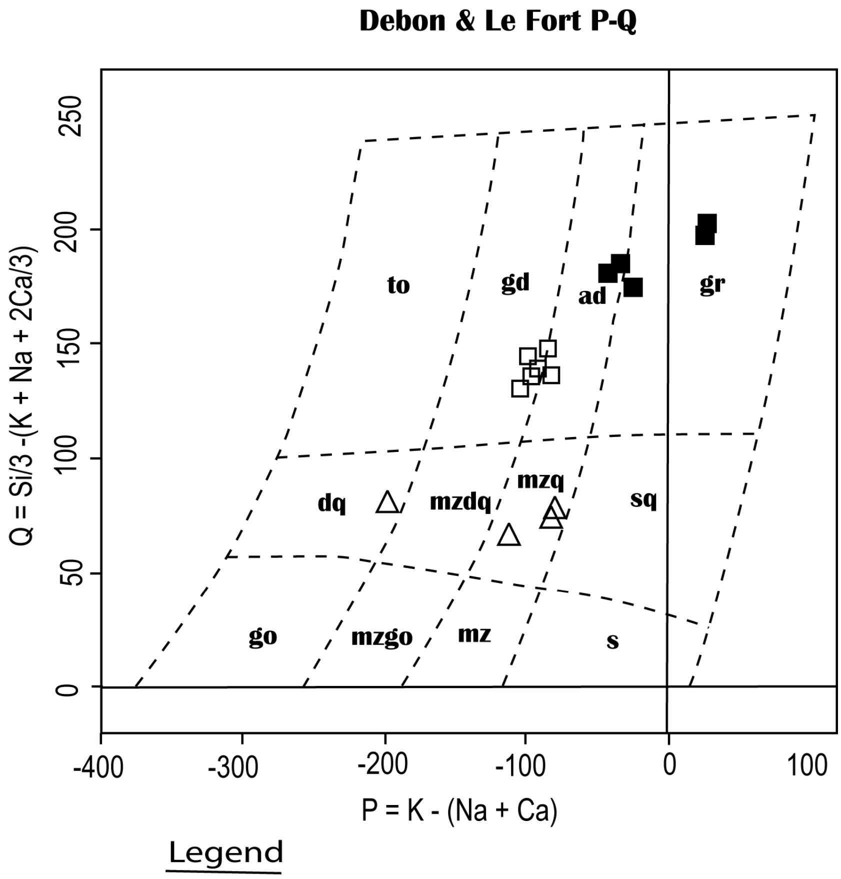

Figure 3. P vs. Q Diagram of Debon and Le Fort (1983) showing the position of granitoid of the Yoro- Yangben area

deformation D_1 and D_2 which precede a mainly breakable D_3 phase. The D_1 phase is regarded by these authors as responsible of regional foliation. Thereafter, Mvondo (2009), showing that the "Bafia gneisses" are affected by three phases of ductile deformation D_1-D_3: two compressive phases D_1 and D_3 with maximum shortening E-W to NW-SE and a decompressive phase D_2 with maximum extension NS to NE-SW. The fourth phase of deformation which is mostly brittle is characterized by a conjugate double fault network.

METHODOLOGY

The whole rock geochemical analyses (major, traces and o rare earths elements) were carried out at laboratory SGS-GEOSOL of Vespasiano in Brazil by ICP-OES and ICP-MS with use of the lithium metaborate for fusion. All the major elements and certain trace elements (Sr, Zn, Zr, V) were obtained by ICP-OES and the others trace elements and rare earths elements by ICP-MS. The Rb, Sr, Sm and Nd contents of the samples were determined by XRF and by isotopic dilution at the Geochronology Research Centre of the University of São Paulo (CPGeO-USP) in Brazil. All the proportions of isotopes were measured using a mass spectrometer VG-354 CP Geo. A technique of two columns was used for the Sm- Nd analyses. Firstly, exchanging resin anions was employed for separation of rare earths elements and the HDEHP (Acid di (2-ethylhexyl) phosphoric) was used for the separation of Sm and Nd. The details of the analytical procedures are reported in Santos (1995).

The analyses of the standards Nd and Sm gave maximum values of 70 and 30pg respectively. The average measurement of the values 143Nd/144Nd of the standards of Jolla and BCR-1 are 0.511849 0.000025 and 0.512662 0.000027 respectively, with error of 1 sigma. Model ages T_{DM} (Texeira *et al.*, 1996) were calculated using the model of the parameters of De Paolo (1981): a = 0.25; b = -3; c = 8.5 and normalized isotopic ratios ^{147}Sm/^{144}Nd = 0.7219; isotopic ratios [^{143}Nd/^{144}Nd. (CHUR) 0=0.512638 and ^{147}Sm/^{144}Nd (CHUR) 0=0.967]. The values of Nd were calculated according to Rollinson (1993). Calculations of the age for the Rb/Sr analyses used decay constants recommended by Steiger and Jäger (1977). The determinations of Rb and Sr on the samples without addition of standards were measured by fluorescence of the X-rays with precision of roughly 2%. The values of the analyses of dilution of the isotopes were obtained on the samples having Rb and Sr contents lower than 50ppm and higher than 500ppm respectively.

RESULTS

Petrography

Chemical (Fig.3) classification of Debon and Le Fort (1975) P = K - (Na + Ca) vs. Q = Si/3 - (K + Na + 2Ca/3) allowed to subdivide orthogneisses in three types namely: granite, granodiorite and quartz-monzonite.

Granodiorite

Orthogneiss with megacrystals of alkaline feldspar and a composition of granodiorite constitute the main rock of Yoro-Yangben area and represent approximately 90% of the rock in the massif. This rock out crops as dome (Fig. 4). In the outcrop, the rock is dark-gray or pink-gray and show a gneissic layering underlined by the alternation of dark layers rich in amphibole, biotite and of the leucocratic layers (Fig. 5A). These layers show porphyroblasts and/or porphyroclasts reaching 7cm length on 4cm width. These feldspars display ovoid, sigmoid or fish shape and are preferentially elongated (Fig. 5A). Under the microscope, the rock displays a protomylonitic microstructure (Fig. 5B, C and D) and consists of quartz (20-25%), alkaline feldspars (5-10%), plagioclase (45-55%), biotite (5-10%), pyroxenes (≤5%) and the amphibole (≤3). The accessories minerals are the opaque minerals (Fig. 5F), titanite and zircon. The ferromagnesians are of millimetre-length size (Fig. 5D). Typical associations (Fig. 5) are with Quartz + alkaline Feldspar + Plagioclase + Hornblende + Biotite + Pyroxene + Titanite.

Granite

Leucocrate orthogneiss with composition of granite are richer in alkaline feldspar than the granodiorite. They are interbedded in the granodiorite (Fig. 6A and B). It is a pink clear rock with oriented minerals. In the field, the rock is made up of quartz, feldspar and biotite. Quartz and the feldspar are the deformed crystals and of millimetre-length size (2 X 5 mm). In thin section, the rock show a heterogranular granoblastic microstructure (Fig.6C) and consist of quartz (30-40%), alkaline feldspar (20-30%) showing peripheral granulations (Fig. 6D) and varied shapes (Fig. 6E and F), plagioclase (10-15%), biotite (10-15%), and accessories are titanite, apatite, zircon and opaque phases. The passage to previous orthogneiss is done by a level rich in biotite (Fig. 6G). Mineral associations are Quartz + Alkaline feldspath + Plagioclase + Biotite + Titanite.

Quartz monzonite

Quartz monzonite out crops as symmetrical domes (Fig. 7A) or in ovoid, and angular blocks of metric to plurimetric size in the Yangben locality. The rock is of gray color slightly pink. In the naked eye, the rock shows orthoclase with pink color (1-8cm length) abundant and of ovoid, elongated, sigmoid or oriented almond shapes. The quartz crystals are stretched (2mm-6mm) and are oriented. Titanite and lamellae biotite are also oriented. Under the microscope, the rock has a granoblastic and protomylonitic microstructure (Fig. 7B, C) and is made up of quartz (2 6%), alkaline feldspars (10-15%), plagioclase (15 20%) showing deformed twins (Fig. 6C and D), large crystals (Fig. 6C and E) of amphibole (10 33%), pyroxene (22-39%) and biotite (19 25%). The opaque minerals (≤5%), titanite (≤ 1%), apatite (≤ 1%) and zircon (≤1%) are the accessories phase. Quartz + Alkaline feldspar + Plagioclase + Pyroxene + Biotite ± Hornblende+ Titanite is the most frequent association.

SHEARING MARKERS IN THE YORO-YANGBEN AREA

The field observations and the petrographic study allowed highlighting, on various scales, several markers of shearing, linked to the major tectonic phase of the study area. The shearing criteria are numerous (Fig. 8 and 9) and a large variety of kinematics indicators were observed such as (i) asymmetric boudins (Fig. 8), (ii) rotations of pressure shadow rich in quartz, (iii) S-C fabrics (Fig. 9), rolling structures of feldspars like δ-structure, σ- and φ-structures (Fig. 9), all indicating a sinistral direction of shearing.

Figure 4. Overall picture of orthogneisses in the Yoro careers

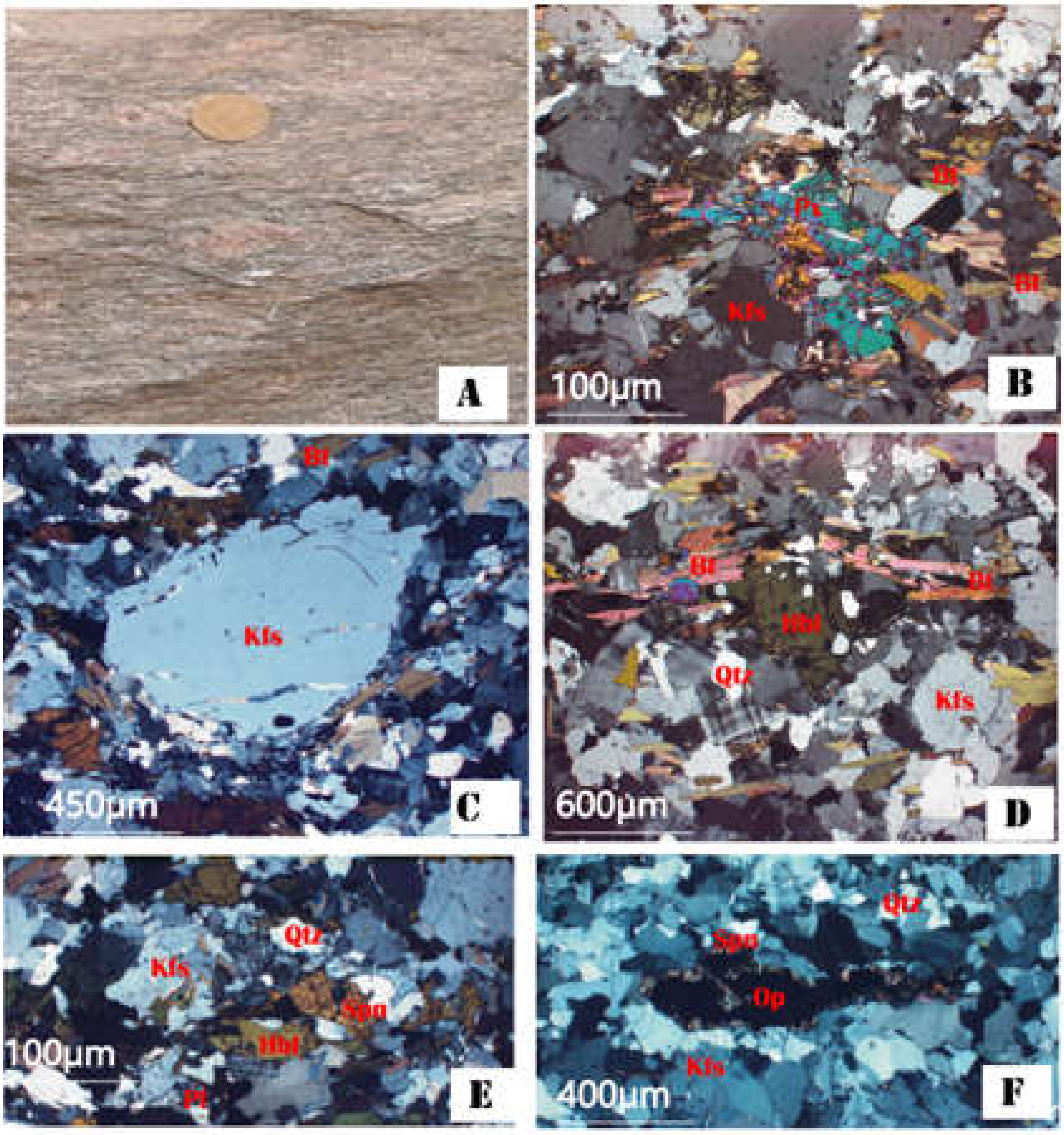

Figure 5. Macroscopic and microscopic Aspects of amphibole and megacrystals alkaline feldspar rich orthogneiss (granodiorite). A. An aspect of megacrystals alkaline feldspar rich orthogneiss. Note the big size of porphyroclasts. B. Protomylonitic Microstructure of megacrystals alkaline feldspar rich orthogneisses. C. Ovoid shape of alkaline feldspar preferentially oriented. Note the peripheral granulations. D. Layers rich in amphibole and biotite lamellae. Note the orientation of the lamellae. E. Hornblende + Quartz + Alkaline Feldspar + Plagioclase + Titanite + Biotite. F. Destabilisation of titanite into opaque minerals.

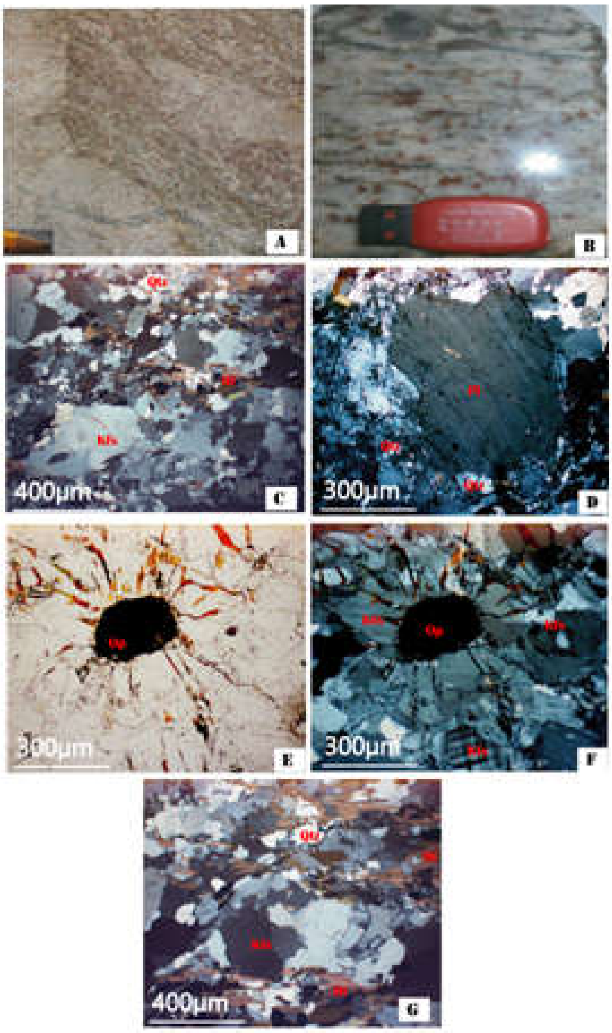

Figure 6. Macroscopic and microscopic Aspects of leucocratic orthogneisses (granite). A and B. interbedded leucocratic orthogneiss in the granodiorite. Note the orientation of the minerals and spotted aspect of the rock due to the pink spot. C. Heterogranular granoblastic Microstructure and mineralogical composition. D. Peripherals granulations with quartz around plagioclase. E and F. Sub-euhedral Small crystals of alkaline feldspar and opaque. G. Concentration of the biotite lamellae to the contact with megacrystals alkaline feldspar orthogneiss.

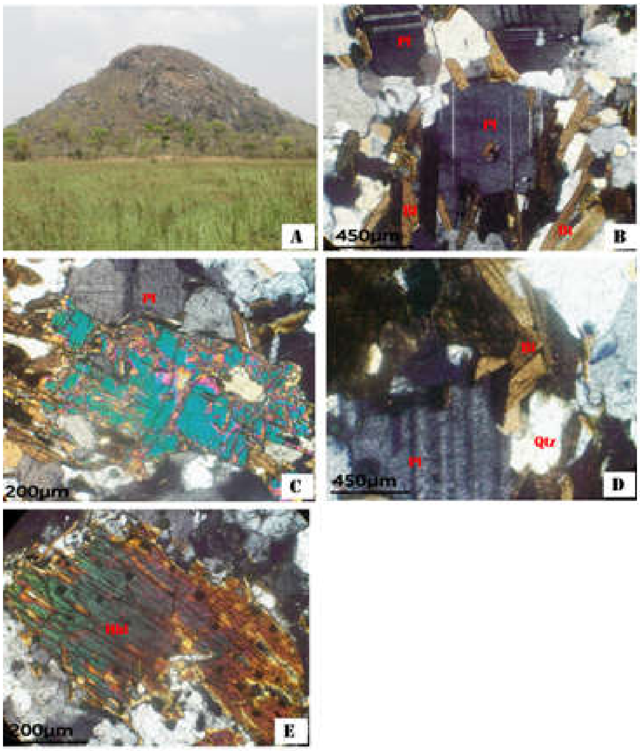

Figure 7. Macroscopic and microscopic aspects of quartz-monzonite. A. Quartz-monzonite symmetrical dome of the Yangben area. B and C. granoblastic Microstructure and mineralogical composition. C and D. Kink deformation of the plagioclase twins. E. Large amphibole Crystal

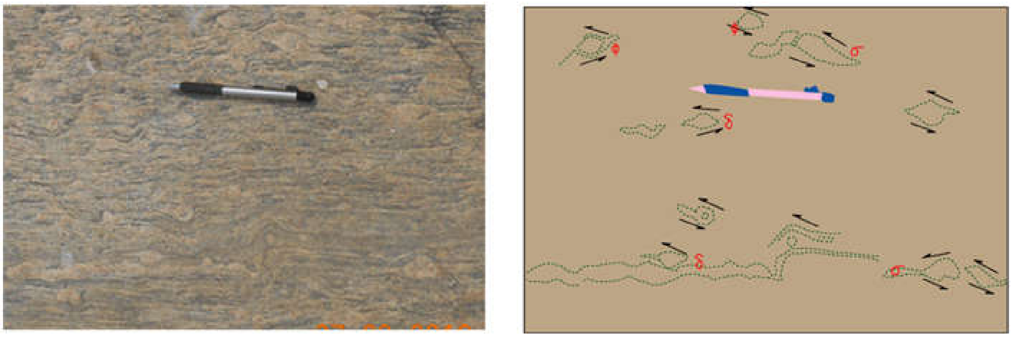

Figure 8. Mylonitic microstructures indicating the shear in the Yoro-Yangben orthogneisses

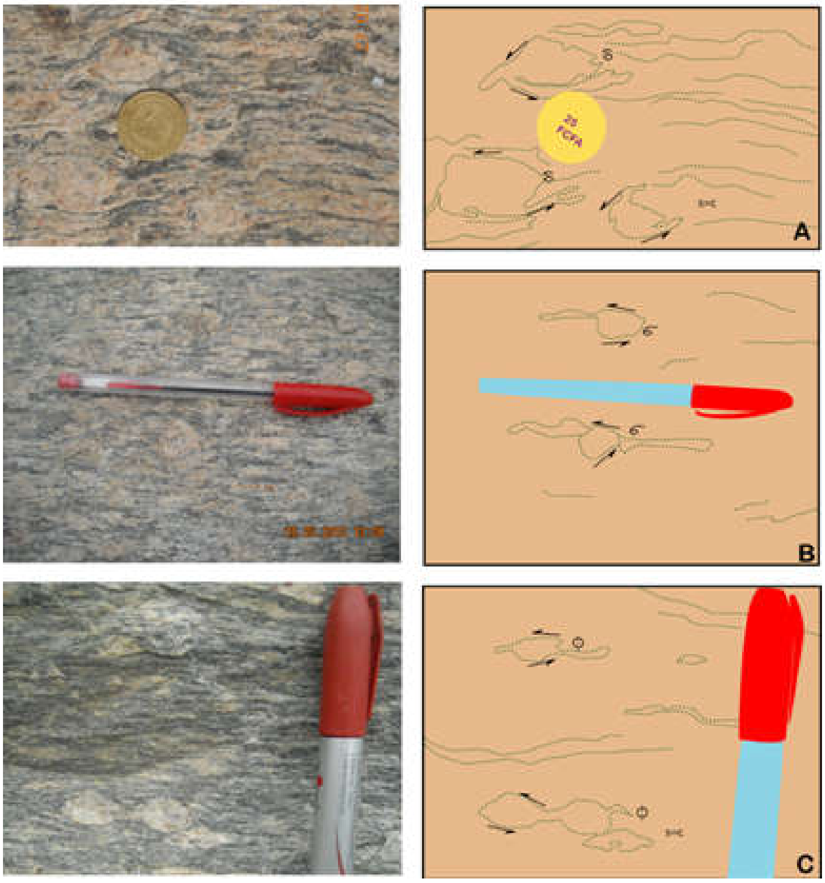

Figure 9. Typical mylonite structures: δ, σ, φ, with sinistral polarity in the Yoro-Yangben orthogneiss

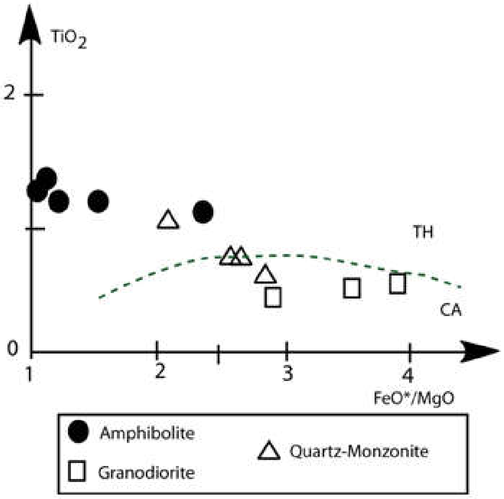

Figure 10. TiO_2 vs. FeO*/MgO Diagram showing the calc-alkaline and tholeiitic affinities of granitoid and amphibolites of Yoro-Yangben. The limit between the tholeiitic and the calc-alkali field is of Miyashiro (1975)

GEOCHIMISTRY

Major elements

The rocks are of variables composition (granodioritic; granitic and monzonitic; Table 1) with the silica contents of (SiO_2) from 59.2 to 76.10% and alumina (Al_2O_3) from 11.73 to 15.6%. The iron contents (1.54 -3.91%) and CaO (0.61-5.67%) are variable. Alkaline contents (Na_2O: 2.68 to 4.31% and K_2O: 3.7 to 5.94%) are less variable; these rocks are more potassic than sodic (Table 1). The TiO_2 contents of these rocks are low (0.29-1.05%) and characteristic of the rocks of the calc-alkaline series. The variation of iron and titanium versus FeO*/MgO ratios (Fig. 10) as well as the higher (>40 on average) Al_2O_3/TiO_2 ratios (26-175) are in accordance with those of the calc-alkaline rocks. These rocks have low MgO contents (0.05-0.57%) and consequently the FeO*/MgO ratios (3-38) are very high, which confirms their belonging to ferriferous series. K_2O vs. SiO_2 Diagram (Fig. 11A) shows that these rocks are calc-alkaline and belong to the field of the hyperpotassic calc-alkaline rocks with some rocks belonging to the shoshonitic series. In the A/NK vs. A/CNK diagram (Fig. 11B), the rocks are mainly metaluminous and of I-type (Chappell and White, 1974). The examination of the variation diagrams of some major elements versus SiO_2 (Fig. 12) shows a grouping for each type of rocks and an evolutionary *trend* marked by negative correlations of Al_2O_3, TiO_2, Fe_2O_3, CaO, Na_2O, MgO and P_2O_5.

Tableau 1. Major (wt%) and trace (ppm) elements data for representative rocks of Yoro-Yangben area

	Granite					Granodiorite						Quartz Monzonite				Amphibolite		
%	YAN	YANA	NK5C	NK5B	NK5	NK2	NK2A	NK8	NK5A	BOG2A	NK8A	YA1	BOG	BOG2	BOG A	NK3	NK3A	NK3E
SiO2	75.09	74.5	76.1	75.5	72.68	69.4	69.41	69.3	69.9	68.6	68.1	59.3	59.5	59.2	60.8	47.2	46.78	46.91
Al2O3	12.2	11.73	12.26	12.07	13.75	13.05	15.22	15.6	14.5	15.5	14.6	15.4	14.75	15.25	14.5	20.36	18.3	19.2
TiO2	0.23	0.33	0.07	0.08	0.29	0.5	0.46	0.6	0.29	0.42	0.52	1.05	0.75	0.78	0.65	1.18	1.44	1.22
Fe2O3	2.19	3.2	2.09	1.54	2.2	3.91	3.09	3.01	2.94	3.03	3.87	7.33	7.47	7.27	7.33	10.15	8.99	9.19
MnO	0.05	0.06	0.02	0.02	0.02	0.1	0.05	0.04	0.07	0.09	0.08	0.12	0.75	0.78	0.65	0.19	0.16	0.14
MgO	0.29	0.41	0.05	0.07	0.57	0.98	0.93	0.68	0.54	0.44	0.49	3.06	2.5	2.53	2.3	3.71	7.18	6.83
CaO	0.98	1.22	0.61	0.64	1.38	2.58	2.26	2.09	2.17	2.23	2.88	5.67	4.31	4.82	4.67	7.3	9.96	8.71
Na2O	3.65	3.69	2.68	2.72	3.3	4.07	3.94	4.18	4.31	4.25	4.12	4.31	3.27	3.59	3.12	4.81	4.01	4.39
K2O	4.83	4.67	5.92	5.94	5.01	3.97	3.89	4.15	3.7	3.82	3.76	2.01	4.74	4.23	4.89	1.96	1.41	1.57
P2O5	0.04	0.33	0.01	0.01	0.09	0.17	0.14	0.13	0.09	0.11	0.56	0.31	0.46	0.49	0.32	0.47	0.24	0.3
LOI	0.34	0.38	0.79	0.91	0.26	1.44	0.4	0.42	1.13	1.07	0.87	1.47	1.03	1.04	0.94	2.87	1.82	2.06
Total	99.89	100.52	100.6	99.5	99.55	100.17	99.79	100.2	99.64	99.56	99.85	100.03	99.53	99.98	100.17	100.2	100.29	100.5
Na2O + K2O	**8.48**	**8.36**	**8.6**	**8.66**	**8.31**	**8.04**	**7.83**	**8.33**	**8.01**	**8.07**	**7.88**	**6.32**	**8.01**	**7.82**	**8.01**	**6.77**	**5.42**	**5.9**
FeO*/MgO	**6.80**	**7.02**	**37.62**	**19.80**	**3.47**	**3.59**	**2.99**	**3.98**	**4.90**	**6.20**	**7.11**	**2.16**	**2.69**	**2.59**	**2.87**	**2.46**	**1.13**	**1.2**
Al2O3/TiO2	**53.04**	**35.55**	**175.14**	**150.88**	**47.41**	**26.10**	**33.09**	**26.00**	**50.00**	**36.90**	**28.08**	**14.67**	**19.67**	**19.55**	**22.31**	**17.25**	**12.71**	**15.7**
A/CNK	**0.94**	**0.88**	**1.03**	**1.00**	**1.03**	**0.83**	**1.03**	**1.03**	**0.96**	**1.02**	**0.91**	**0.79**	**0.80**	**0.79**	**0.77**			
ppm																		
Ba	591	623	175	181	978	1185	1020	1661	1140	1270	1679	900	1905	1875	1855	1935	1517	1905
Cr	10	10	10	9	9	708	701	669	690	689	657	30	30	20	25	10	8	10
Ni	<1	1	1	1	7	1	5	6	3	3	6	14	6	4	6	5	52	4
Mo	1	1	1	1	2	1	3	1	<1	1	2	<1	1	1	1	<1	1	1
Nb	10.6	9.8	1.3	1.7	7.51	14.4	12.21	10	11	11	10	11.9	11	10.8	9.57	8.6	5.54	6.82
Rb	111	101	166	165	131	104	128	103	131	129	123	60.7	158	117.5	167	63	33.3	54.76
Sr	123	222	74	71	84	371	278	345	243	247	380	861	989	1140	989	970	1050	870
Sn	3	4	1	1	0.8	3	1.4	1.8	1	1	1.9	2	2	2	2	3	1.8	2.3
U	0.65	0.69	2.24	2.38	1.11	0.98	1.83	0.88	2.33	2.05	0.81	0.5	0.78	0.72	0.65	0.63	0.84	0.54
Y	13	19	1	2	10	23	18	32	11	12	31	25	29	28	28	35	19	29
Zn	44	41	16	7	29	57	42	41	33	35	47	82	94	94	93	124	91	108
Zr	149	152	71	61	111	245	183	407	152	158	335	195	248	232	227	368	46	277
Hf	4.5	5	3.2	2.7	3.11	6.5	4.84	8.77	4.3	4.8	7.94	5	6.5	5.7	6.89	8.1	1.75	3.23
Ho	0.47	0.38	0.03	0.05	0.36	0.8	0.66	1.34	0.39	1.66	4.58	0.83	1.04	1.05	6.23	1.2	0.75	0.87
Pr	4.95	6.98	1.48	1.71	4.32	10.05	9.1	19.26	6.22	7.28	20.19	8.85	10.55	11.4	12.78	10.85	5.71	9.45
Ta	0.5	0.7	0.1	0.1	<0,05	1	0.27	<0,05	0.7	0.7	<0,05	0.8	0.8	0.7	0.8	0.3	<0,05	0.02
Tb	0.34	0.64	0.03	0.03	0.29	0.6	0.58	1.4	0.28	0.35	1.8	0.74	0.94	0.9	1.1	1.08	0.65	0.09
Th	20.2	18.2	34.4	37.3	13.3	18.2	15.8	8.8	22.1	21.2	10.57	3.52	3.02	3.27	3.15	1.81	2.5	2.03
Tm	0.2	0.23	0.03	0.03	0.16	0.34	0.28	0.45	0.16	0.19	0.41	0.36	0.42	0.39	0.44	0.51	0.29	0.34
Pb	19	16	23	19		16			17	18		6	19	20	18	7		7
Zr/Y	11.3	7.9	50.7	40.7	10.9	10.6	10.1	12.6	13.9	13.1	10.8	8.0	8.6	8.3	8.1	10.5	2.4	9.7
Zr/Nb	14.1	15.5	54.6	35.9	14.8	17.0	15.0	41.4	13.3	14.1	32.5	16.4	22.5	21.5	23.7	42.8	8.3	40.6
Rb/Sr	0.9	0.5	2.2	2.3	1.6	0.3	0.5	0.3	0.5	0.5	0.3	0.1	0.2	0.1	0.2	0.1	0.0	0.1
La	24.4	25.7	21	23.8	32.5	53.5	56.1	82.6	50.1	49.3	80.8	38.2	41.3	49.3	44.7	42.9	25.2	27.71
Ce	53.6	50.6	23.4	26.1	46.6	99.9	87.3	162.6	73.7	74.1	132.8	73.4	84.9	94.9	86.1	91.1	46.6	87.3
Sm	2.33	1.28	0.51	0.57	2.3	5.64	4.8	12.9	2.94	2.45	9.87	7.79	8.94	8.65	8.77	8.67	5	8.9
Nd	16	20	4	3.8	13.5	36.3	30.2	70.5	20.1	22.4	68.9	38.3	44.9	46.9	47.2	47.1	23.3	44.3
Eu	0.56	1.7	0.35	0.31	0.63	1.24	1.03	2.17	0.64	0.53	2.15	1.97	2.13	2.15	2.19	2.66	1.49	2.07
Gd	1.69	0.98	0.36	0.38	2	4.27	3.82	9.93	1.73	2.41	8.53	5.23	6.4	6.72	5.36	7.75	4.5	6.46
Dy	2.13	3.12	0.21	0.25	1.81	3.81	3.25	7.39	1.71	1.66	4.58	4.22	5.44	5.15	6.23	6.31	3.8	4.9
Er	1.19	2.15	<0,03	0.13	1.02	2.3	1.86	3.39	1.02	1.45	2.87	2.11	2.65	2.59	2.77	3.14	1.93	3.02
Yb	1.5	1.88	2.64	0.18	1.2	2.66	2.1	2.5	1.44	1.92	2.39	1.81	2.48	2.81	2.64	3.14	1.8	2.5
Lu	0.25	0.36	0.05	0.04	0.21	0.43	0.34	0.37	0.26	0.28	0.29	0.29	0.36	0.41	0.23	0.51	0.26	0.38
(Ce/Sm)N	0.81	0.61	1.41	1.66	0.83	0.66	0.70	0.56	0.89	0.80	0.47	0.46	0.46	0.49	0.44	0.47	0.48	0.4
(La/Yb)N	10.98	9.23	5.37	13.61	18.28	13.58	18.03	22.30	23.48	17.33	22.82	14.25	11.24	11.84	11.43	9.22	9.45	7.4
(Gd/Yb)N	0.91	0.42	0.11	0.26	1.35	1.30	1.47	3.21	0.97	1.01	2.88	2.34	2.09	1.93	1.64	1.99	2.02	2.0
Eu/Eu*	**0.33**	**1.17**	**0.89**	**0.79**	**0.37**	**0.30**	**0.29**	**0.25**	**0.33**	**0.22**	**0.27**	**0.43**	**0.38**	**0.37**	**0.42**	**0.43**	**0.44**	**0.3**

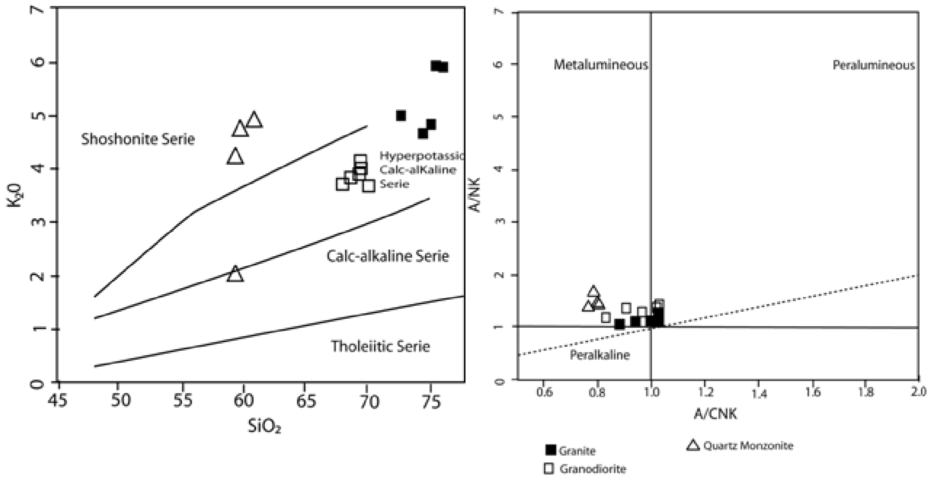

Figure 11. (a): SiO_2 vs. K_2O Diagram (Chappell and White, 1974) showing shoshonitic and hyperpotassic calc-alkaline affinity rocks of the Yoro-Yangben rocks; (b): molar diagram A/NK vs. A/CNK showing metaluminous and low peralumineous affinity of the Yoro-Yangben rocks

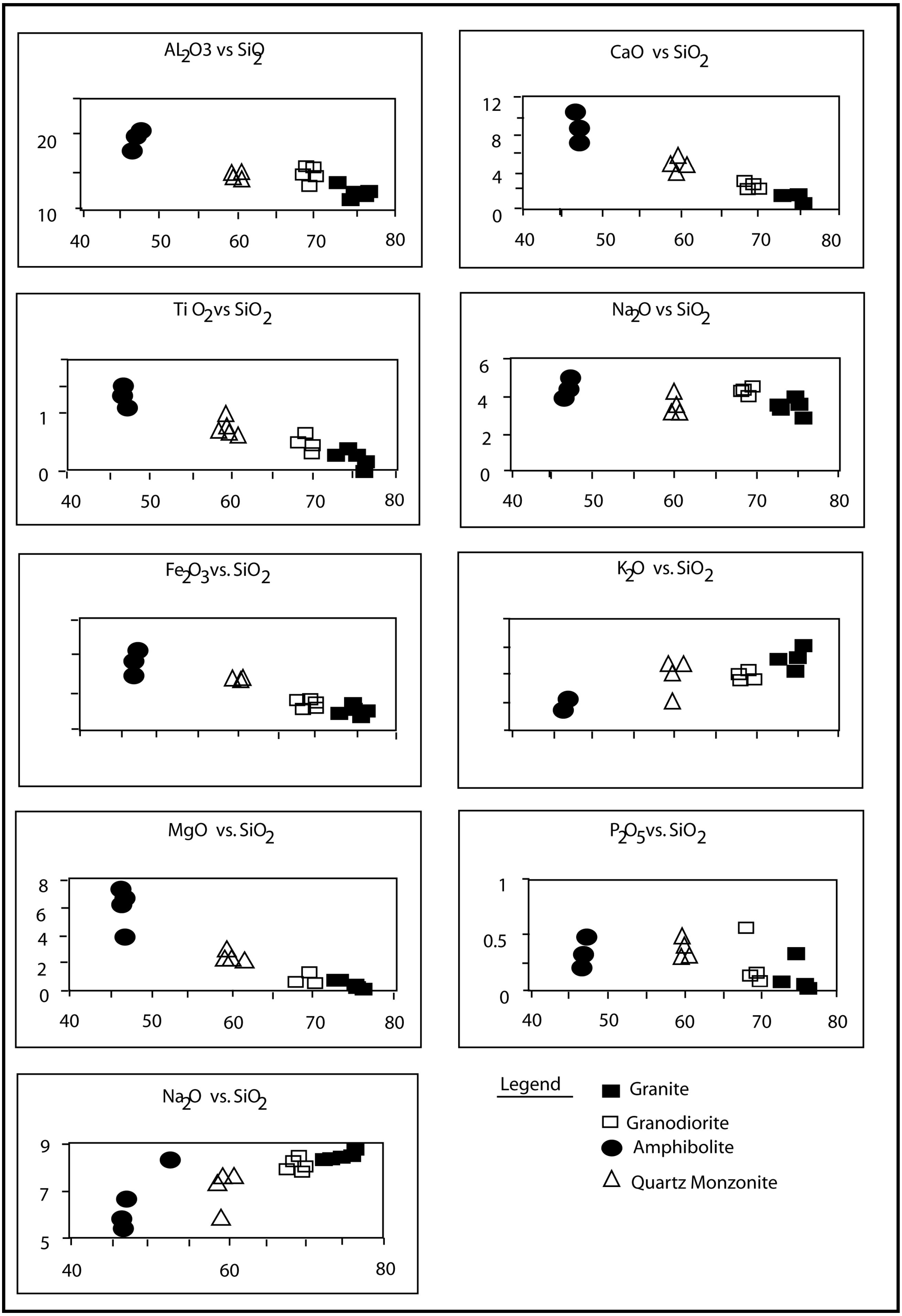

Figure 12. Variation diagrams vs. SiO2 of some major elements of Yoro-Yangben rocks.

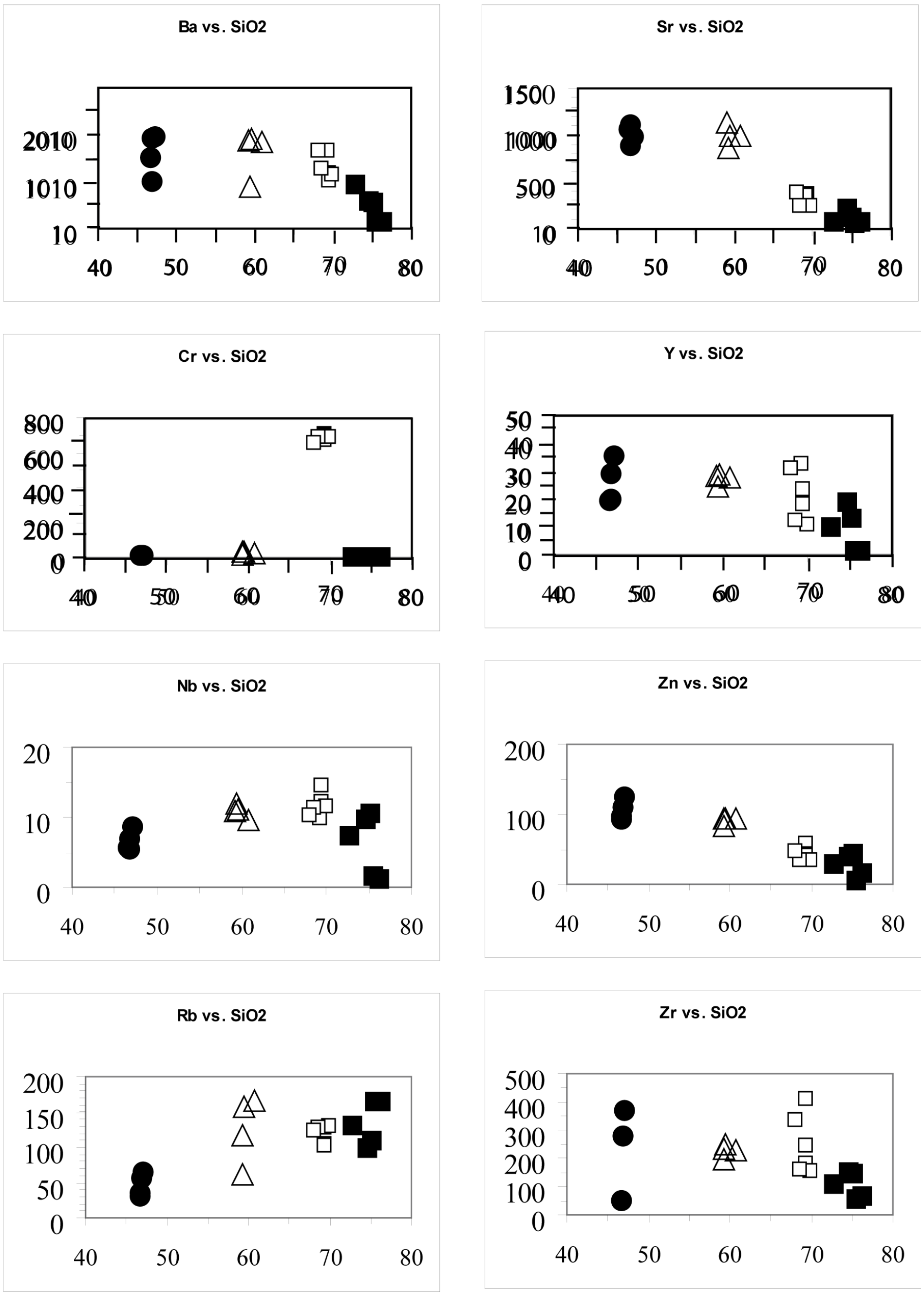

Figure 13. Variation diagrams vs. SiO_2 of some trace elements the Yoro-Yangben rocks. Symbols as in Fig. 12

Tableau 2. The calculated temperatures using Zr saturation geothermometer (Harrison and Watson, 1983; Watson and Harrison, 1983)

Num Ech.	Zr ppm	T°C
Granite		
YAN	149	773
YANA	152	768
NK5C	71	724
NK5B	61	710
NK5	111	755
Granodiorite		
NK2	245	795
NK2A	183	793
NK8	407	867
NK5A	152	771
BOG2A	158	779
NK8A	335	832
Quartz Monzonite		
YA1	195	749
BOG	248	774
BOG2	232	764
BOG A	227	762

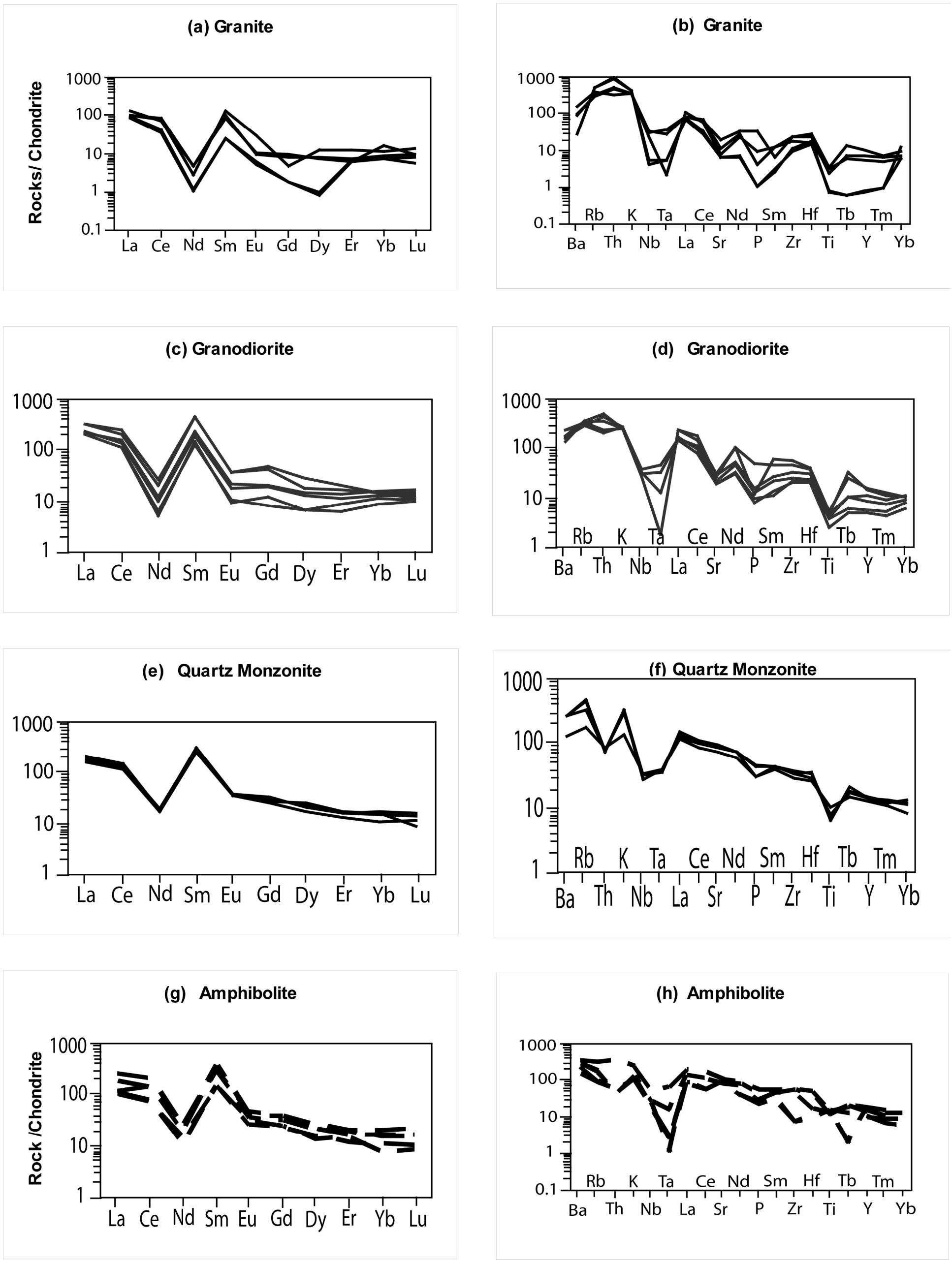

Figure 14. REE (a, c, e, g) and multi-elements (b, d, f, h) patterns of Yoro-Yangben rocks

Trace elements

The concentrations of the trace elements in the Yoro-Yangben massif are presented in Table 1. lithophile elements contents Ba (1020-1905ppm; 900-1905ppm), Sr (243-407ppm; 861-1140ppm), Zr (152-407ppm; 195-248ppm) and Rb (103-129 ppm; 61-167 ppm) of the granodiorites and quartz-monzonites respectively and those of the granites Ba (175-978 ppm), Sr (71-222 ppm), Zr (61-152 ppm) and Rb (101-166 ppm) are high and moderate, compatible with a strong fractionation of feldspars and zircon and comparable with those of the calc-alkaline rocks (Thompson and al., 1984). The Zr/Y ratios (8-14) are high compared to those of Nb/Y (≤ 1) and similar to those of the calc-alkaline series. Variation diagrams of some trace elements versus SiO2 (Fig. 13) shows an evolutionary trend marked by a regrouping. The REE patterns (Fig. 14) show that these rocks are fractionated ($La_N/Yb_N = 5\text{-}18$) with a light enrichment of LREE (Ce_N/Sm_N= 0.4-1.4), of HREE (Gd_N/Yb_N= 0.1-2.34) and significant negative europium anomalies in all the petrographic types: (Eu/Eu*=0.33-0.89) for the granite, (Eu/Eu* = 0.22-0.33) for the granodiorites and (Eu/Eu* = 0.37-0.43) for quartz-monzonite. The multi-elements patterns (Fig. 14) display the negative anomalies of Nb, Ta and Ti characteristics of the rocks of crustal origin (Thompson *et al.*, 1984).

EMPLACEMENT CONDITIONS

Saturation zirconium geothermometry

We applied the geothermometer of the saturation zirconium (Harrison and Watson, 1983; Watson and Harrison, 1983) to granitoid of Yoro-Yangben to estimate the minimum temperatures of melting. The calculated temperatures (Table 2) are of 710 - 768ºC for the granite, 771-867°C for the granodiorite and 749 - 774°C for quartz-monzonite. Granodiorite and granite have the temperatures in accordance with those of peraluminous crustal granite.

ISOTOPIC GEOCHEMISTRY

The results of the isotopic data are gives in Tables 3 and 4. The granodiorite have isotopic ratios $^{87}Sr/^{86}Sr$ of 0.7089 to 0.7143,

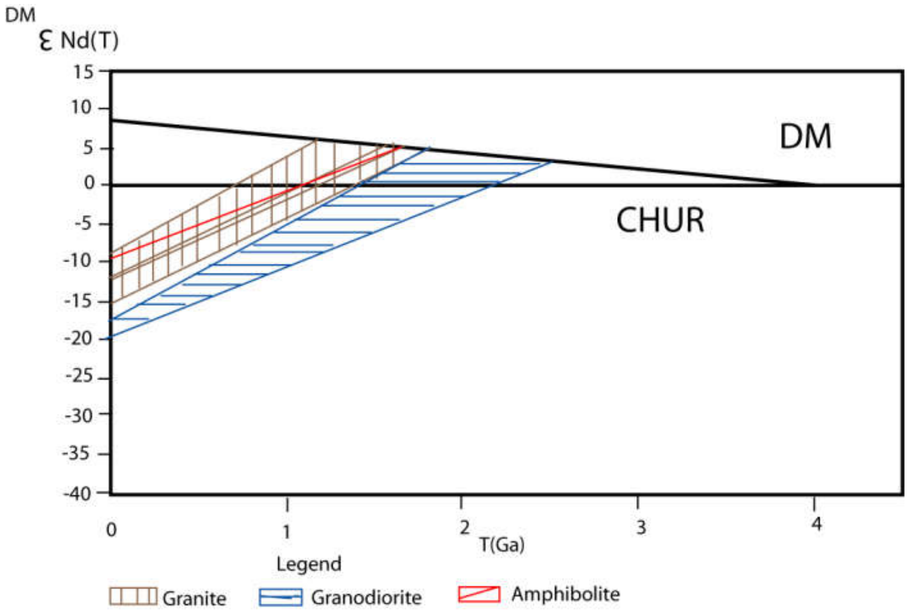

Figure 15. Neodymium evolution diagram vs. time (of billion years) for the CHUR model and the DM (Depleted Mantle) model, note the horizontal evolution of the CHUR (normalized with itself = 0), and the second degree polynomial evolution of the DM (0,25t^2 - 3t + 8.5 with T in Ga according to De Paolo (1981), of the Yoro-Yangben rocks showing the relations between the granite (brown), granodiorite (blue) and amphibolite (red)

Tableau 3. Isotopic composition of Sr in selected samples from Yoro-Yangben area

Ech. N°	(87Sr/86)	(87Rb/86Sr)	(RSr)i	Sr(0)	Sr(T)	T(Ma)	Rb(ppm)	Sr(ppm)
Granite								
NK5	0,720923	2,076990	0,703151	233	-9,11	600	131,2	183
NK5-a	0,71543	2,103489	0,697432	155	-90,40	600	130,1	184
Granodiorite								
NK2	0,714312	1,147265	0,704496	139	9,99	600	127,6	322
NK2-a	0,71279	1,128397	0,703135	118	-9,34	600	126,1	322
NK8	0,712679	0,782859	0,705981	116	31,09	600	102,5	379
NK8-a	0,70889	0,22489	0,706966	62	45,09	600	103,1	377
Amphibolite								
NK3	0,705602	0,152897	0.705145	16	19	2100	33,3	630
NK3-a	0,707301	0,170734	0.706791	40	43	2100	33,6	634

Tableau 4. Isotopic composition of Sm/Nd in selected samples from Yoro-Yangben area

Ech. N°	^{147}Sm/^{144}Nd	^{143}Nd/^{144}Nd	R(Nd)i	$\varepsilon_{Nd(0)}$	$\varepsilon_{Nd(T)}$	TDM (Ga)	T(Ma)	Sm (ppm)	Nd (ppm)
Granites									
NK5	0.0950	0.5122	0.51183	-8.51	-0.75	1.22	600	2.1431	13.6359
NK5-a	0,0935	0,5198	0.51943	139.75	147.84	-8.71	600	2,1132	13,4554
Granodiorites									
NK2	0.0970	0.5122	0.51182	-8.51	-0.91	1.24	600	4.2505	26.5038
NK2-a	0,175	0,5134	0.51271	14.90	16.55	-0.99	600	4,2213	25,6783
NK8	0.1041	0.5123	0.51189	-6.55	0.50	1.18	600	12.0327	69.8967
NK8-a	0,1023	0,5113	0.51090	-26.06	-18.90	2.52	600	12,0244	68,6547
Amphibolites									
NK3	0.1247	0.5124	0.51223	-4.60	7.10	1.28	2100	4.4474	21.5679
NK3-a	0,0981	0,5122	0.51207	-8.51	3.91	1.25	2100	4,2213	21,5345

^{143}Nd/^{144}Nd of 0.5113 to 0.5134. The initial ratios ^{87}Sr/^{86}Sr vary between 0.7039 to 0.7059, ^{143}Nd/^{144}Nd of 0.5109 - 0.5127 and ε_{Nd}(T) from -18.90 to 16.55. The granite have isotopic ratios ^{87}Sr/^{86}Sr of 0.7154 – 0.7209, ^{143}Nd/^{144}Nd of 0.5198 to 0.5122. The initial ratios ^{87}Sr/^{86}Sr varies from 0.6974 to 0.7031, ^{143}Nd/^{144}Nd of 0.5118 - 0.5194 and ε_{Nd}(T) from -0.75 to 148. The variation of the initial isotopic ratios ^{87}Sr/^{86}Sr in the granite and the granodiorites is indicative to the heterogeneity of their source. These initial ratios of Sr are high and suggest a parental magma issued from a crustal source with high ^{87}Sr radiogenic contents.

DISCUSSION

This discussion concerns the petrographic, structural, and geochemistry aspects.

LITHOLOGY

The formations of the Yoro-Yangben massif consist of a monocyclic lithological unit. This unit is made of amphibole and megacrystals of orthoclase rich orthogneiss (granodiorite), megacrystals of orthoclase rich leucocratic orthogneiss (granite), pyroxene and megacrystals of orthoclase orthogneiss (quartz-monzonite) and, of amphibolites. There are no notable lithological differences between the Pan African granitoids of the Cameroonian central domain and the magmatic rocks of Yoro-Yangben. On the other hand the rocks of Yoro-Yangben show differences with meta-igneous of Yaoundé, in so far as the first are calc-alkaline and tholeiitic, and seconds are alkaline.

PETROGENETIC ASPECTS

The geochemical behaviors show that the Yoro-Yangben rocks are similar to those of the hyperpotassic calc-alkaline series of the orogenic domain. Orthogneiss show very significant negative Europium anomalies underlining the role of the plagioclase in the differentiation process of these rocks. They have high contents of Light Rare Earths Elements and low content in Heavy Rare earths elements. The very high contents of LREE is due to the abundance of pyroxenes, amphiboles and accessories minerals such as titanite, allanite and apatite; whereas the rare notable contents of HREE (*10* to *50* times chondrites) are due to the significant presence of zircon. The linear correlations of the major elements with the SiO2 (Fig.12) and between the different Rare Earths Elements (Fig. 14) testify to an evolution by fractional crystallization as main process prevailing at the origin in the Yoro-Yangben rocks. The rock emplacement under stress due to the working of regional shear zone, produce variations in the magma composition, certainly after a magmatic mixture or, of a crustal contamination. This crustal contamination is underlined by (i) independence Ba-Rb, (ii) enrichment of LREE in rocks compared to HREE, (iii) the high contents of lithophile elements (K, Rb, Sr, Ba), (iv) the negative anomalies of Nb, Sr, TiO2 (Rollinson, 1993) and finally (v) Rb/Sr (*0,1-2,3*) ratios higher than those of the mantellic liquids (*0.03*; Wilson, 1989).

TECTONO-MAGMATIC EVOLUTION

The area of Yoro appears much simpler in its evolution. The distinguished geological formations are characterized by the following tectono-magmatic and metamorphic evolution: (i) magmatic associations with Quartz + Alkaline feldspar + Plagioclase + Pyroxene + Biotite ± Hornblende +Titanite (megacrystals Orthoclase Orthogneiss = Granodiorite); Quartz + Alkaline feldspar + Plagioclase + Biotite + Titanite (leucocratic Orthogneiss = Granite); Quartz + Orthoclase + Plagioclase + Pyroxene + Hornblende + Biotite + Titanite (megacrystals Orthoclase and pyroxene Orthogneiss = quartz-Monzonite); (ii) metamorphic paragenesis with Quartz + Hornblende + Orthoclase + Biotite ± Opaque (Amphibolites = metagabbros).

This Pan African magmatism is distinct from that of the Yaoundé area (alkaline magmatism) but resembles much the conditions defined in the granitoid of the other areas of the central domain of the fold belt. The tectonic evolution is in accordance with an orthogneissification in context of crustal shearing with sinistral movements or in a zone with tangential tectonics. The structures combined with wide regional synforms / antiforms indicate a kinematics nappe with south-westward thrusting movement. The progressive deformation markers of the magmatic state to a solid state, associated with the elongated shape of the massif whose structural directions are concordant with those of regional shearing, indicate a syn-kinematic emplacement compatible with a ductile shear which controls the plutonites emplacement (Nzenti, Tanko Njiosseu, and Nchare Nzina, 2007; Chebeu *et al.*, 2011; Nchare Nzina *et al.*, 2010; Nzenti *et al.*, 2006; Nzenti *et al.*, 2011; Nguiessi *et al.*, 1997; Tchaptchet, Schulz and Nzenti, 2009, Danguene *et al.*, 2014). On the level of entire fold belt, the characters of the main tangential phase are similar and the NNE-SSW shortening field is the same; this field controls not only the earlier Pan African SSW nappe translation of Kekem-Bapa-Tonga-Bafia- Yoro-Yangben, but also the Pan African series of Yaoundé towards the South on the Congo Craton. There is thus unicity of the structural evolution and the Pan African kinematics directions in the fold belt, which well confirms that it is about only one fold belt with distinct domains.

NEOPROTEROZOIC MAGMATISM

The magmatism of the Yoro-Yangben area is mostly a hyperpotassic calc-alkaline magmatism. It is typical of the collisional to post-collisionnel orogenic domains (Black and Liégeois, 1993; Liégeois *et al.*, 1994; Nguiessi *et al.*, 1997; Nzenti *et al.*, 2006; Nzenti *et al.*, 2011). Synthesis of all magmatic data in the Pan African fold belt shows that magmatic activity is dominated by the plutonism. Thus from the volcanism point of view of, we have:

- In North, a bimodal volcanism (tholeiites and quartz-keratophyre) to link, according to Njel (1988), to an extension geodynamic context with thinned crust in possible position of back-arc. However that volcanism which has an acid quartz-keratophyre component and which is emplaced at the top of a thick detrital series with a continental crust basement in an environment of the granulite relics and an important volume of calc-alkaline plutons, is not easily compatible with a back-arc basin;
- In the South and the center, an alkaline volcanism (volcanogenic syn-sedimentary rocks and metabasalt) which continues throughout the history of the fold belt and even later on (Nzenti, et al., 1992). The alkaline nature of this volcanism is compatible not only with the fragmentation in Neoproterozoic of the old continental domain, but also with a type rift environment (Nzenti *et al.*, 1988; Nzenti *et al.*, 1992; Ngnotue *et al.*, 2000; *Ngnotue* et al.*, 2012*)**.**

For the plutonism we have

- in North, a Pan-African (630Ma: U/Pb age on zircon, Toteu et al., 1987) calc-alkaline plutonism syn-D_1 to syn-D_2 (diorite, granodiorite and tonalite) which evokes an accretion field.
- in the Eastern part, Pan African diorites and peraluminous granite (614 ± 41 Ma and 621 ± 13 Ma; Soba, 1989) and orthogneisses (Kankeu, Greiling, and Nzenti, 2009) very abundant at the Cameroon-R.C.A. border (Lassere and Soba, 1976). It is a continental magmatism which evokes a collisional environment;

- in the South and the center, a Pan African syn-D_2 to late alkaline (alkaline syenite and granite) and transitional plutonism in northern edge of the Congo Craton of (Yaoundé series), north of Yaoundé series (Bafia series), in the central part of the fold belt (from Maham to the Tikar plain) and north of the plain.

The alkaline magmatism extends on all the history from the fold belt in the southern and central part and continues a long time after orogenesis (Kankeu *et al.*, 2010). A peculiar character of this plutonism is its abundance and its localization in the field of expression of Cameroonian central shear zones (N70°E and N30°E) since the Paleoproterozoic. Recent work on some magmatic complexes of these zones of shear zones (Tanko Njiosseu *et al.*, 2005; Njiekak *et al.*, 2008; Nchare Nzina *et al.*, 2010; Nzenti *et al.*, 2011; Nono Kouankap *et al.*, 2010; Nzenti *et al.*, 2006; Danguene et al., 2014; Kankeu *et al.*, 2010; Fonkwé Djouka *et al.*, 2007; Nzolang *et al.*, 2003) show that they are syntectonic and syn-collisional Pan-African hyperpotassic calc-alkaline complexes whose Sm-Nd model ages indicate a strong participation of an old crust (1400 - 2100Ma). Our work shows that the limit of the Cameroonian Central domain is in Yangben, because after this area there are no other granitoid massifs and its transition with the Southern domain is done through migmatites of Southern domain of the fold belt (Ngnotué, 1997).

EVOLUTION OF CRUSTAL SOURCES WITH AGE

The TDM ages of studied rocks varying from 1.18 to 2.52Ga (Fig.15), have values at the same time strongly negative and positive of ε_{Nd} (600Ma) from -18.90 to -0.91, and 0.50-16.55 respectively. The strong negative values indicate a long and complex crustal history. The isotopic signature of Nd confirms the presence of relics of Paleoproterozoic crusts in this part of the fold belt (Tanko Njiosseu *et al.*, 2005; Nzenti, Tanko Njiosseu, and Nchare Nzina, 2007 ; Ganwa *et al.*, 2008; Nzenti et al., 1994). These results are compatible with those of recent work (Nzenti, 1998b; Njanko *et al.*, 2006; Nzenti *et al.*, 2006; Nzenti, Tanko Njiosseu, and Nchare Nzina, 2007; Nzenti *et al.*, 2011) which shows that the Pan African granitoid of the Cameroon Central Shear Zone come partly from the melting of an old Paleoproterozoic crust.

IMPLICATIONS FOR THE RECONSTITUTION OF WEST GONDWANA PALEOCONTINENT

One of the major continental assemblies in the geological history is the formation of the Western Gondwanaland from the Pan African to early Paleozoic. This assembly implies wide portions of continental crusts which were deformed differently at the time of the convergence of Central and West Africa, of Amazonia and of Congo-São Francisco Cratons at about 600 Ma (Brito de Neves, 1991; Van Schmus *et al.*, 1995). Central and West Africa is the usual designation of the Eastern part of a mega-fold belt (Brasiliano in the West and Pan African in the East) which extends from central Africa to Brazil. The greatest part, about 2000 000 km^2 is now in Africa.

In fact we cannot better understand the pre-assembly and the assembly history of Gondwana without understanding the geological evolution of Central Africa and the adjacent areas in Brazil. Results of this work and those of recent work (Pimentel *et al.*, 2001; Ferré, Gleizes and Caby, 2002; Piuzana *et al.*, 2003; Neves *et al.*, 2006) on the geodynamic evolution of the center and of the NE Brazil on the one hand and Nigeria on the other hand reinforce the suggestions of former work (Nzenti *et al.*, 1988; Nzenti *et al.*, 1994; Nzolang *et al.*, 2003; Tanko Njiosseu *et al.*, 2005; Nzenti *et al.*, 2011; Danguene *et al.*, 2014), according to which these fold belt underwent the same evolution during Proterozoic. This evolution comprises (i) distension of the Paleoproterozoic crust (2.1Ga), (ii) prevalence of the metasedimentary sequences with Neoproterozoic deposits, (iii) ubiquity of the Neoproterozoic (~650-600Ma) planar structures, and (iv) prevalence of transpressive/transcurrente deformation after 600Ma. The absence of the evidences of the closing of a large ocean in all these regions is not in favor of an interpretation of the Central and South domain of the Pan African fold belt as series of the amalgamated terranes (Njonfang et al., 2008). The destabilization of the old continent builded at the end of Paleoproterozoic/Eburnean orogenesis (Rogers, 1996) gives a simple explanation of these results. One ultimate period of plate's divergence took place in Neoproterozoic, followed immediately by a convergence and a contraction indicating the beginning of the Brazilian-Pan-African orogenesis, which have taken place mostly in intracontinental context.

CONSTRAINTS FOR A MODEL

In the fold belt besides the calc-alkaline magmatism there a:

- an abundant peralumineous plutonism well localized in the Cameroonian Central Shear Zone (N70°E and N30°E) since Neoproterozoic (Nzenti *et al.*, 2011; Abaga et al., 1999);
- an alkaline magmatism during all of the evolution of the fold belt since the early stages until the post-Pan-African stages;
- the geochemical data and the first model ages show that the peralumineous plutonism is related to a crustal melting probably in a of crustal thickening context.

The model presented to justify the presence of a calc-alkaline magmatism in the CPNE in Cameroon haves some limits, in particular the absence of a visible suture, the lack of identification of the compressive continental blocks as well as the thrust types associated with reworking of different branches of regional shears.

Conclusion

The Yoro-Yangben rocks belong to a deformed magmatic unit made up mainly of granodiorite with orthoclase megacrystals, granite with orthoclase megacrystals, quartz- monzonite and metagabbro. The geochemical study shows that the Yoro-Yangben plutonites evolved basically by fractional crystallization, and that the magmatism is hyperpotassic calc-alkaline and typical of the orogenic domain of collisional to post-collisional type. This magmatism is accompanied by another of tholeiitic nature indicating a rift type environment. This duality expresses an environment dominated by the extension (tholeiitic) and compression (calc-alkaline). The kinematics markers associated with the regional deformation (feldspar fish, σ-, δ- and φ-structures of the feldspars) and with S-C fabrics indicate south westward thrusting movements. Progressive deformation, elongated shape of massif parallel to the regional shears, is compatible with a synkinematic emplacement in ductile shears which control the emplacement of the plutonites. The isotopic data indicate a crustal origin of the rocks of Yoro-Yangben. The T_{DM} ages of Sm-Nd point to a heterogeneous source and ε_{Nd} values underlined a major crustal component. The $^{87}Sr/^{86}Sr$ ratios show that the protolite had a short crustal history. The hyperpotassic calc-alkaline character of the magmatism is in a good agreement with a intracrustal thrust context in this segment of the Pan-African north equatorial fold belt in Cameroon. The limit of the Cameroonian central domain is well located in the South of Bafia and passes by Yangben. The Yoro-Yangben rocks in the South East of Bafia by its geochemical characteristics and its synkinematic emplacement context into shear zones is similar to other Neoproterozoic granitoids, syntectonic and calc-alkaline of the West and the East of Cameroon. This plutonism is also similar to those of lithospheric shears of the Eastern Nigeria and the province of Borborema in NE Brazil, especially those of the Damagaram and Pernambuco shears.

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