Geochemical Characteristics of Granitoids (Ho Gneiss) from the Pan – African Dahomeyide Belt, Southeastern, Ghana: Implications for Petrogenesis and Tectonic Setting

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Abstract
The Pan-African Dahomeyide belt exposed in Southeastern, Ghana, consist of granitoid gneisses locally known as Ho gneiss. These rocks are thought to be part of the West African Craton (WAC) which was reworked during the Pan-African Orogeny, and may be time equivalent with the Kara gneisses. Petrographical and whole rock geochemical analyses have been used to evaluate the characteristics, petrogenesis and mode of emplacement of the granitoids. The new data reasonably suggest that the Ho gneiss consist mainly of biotite augen gneisses of both mafic and felsic rock suites. Geochemically, these rocks show tonalitic to quartz monzonite but mainly granodiorites affinities. They are metaluminous to weakly peraluminous, I-type, magnesian to ferroan and calcic to alkali calcic. With these varying features, the granitoids mimic mantle derived magma source which mixed or mingled with crustally derived melt. The rocks display varying REEs and trace elements patterns but, their LREEs and LILE enrichment with the noticeable enrichment in Rb, Ba, K and especially Pb and negative Ti, Ta, Nb observed among majority of the samples are typical signature of ‟arc rocks" or continental crustal materials. Their incompatible trace element ratios, such as Th/U (1.07 – 13.87), K/Rb (272 – 574.47), Th/Yb (0.79 – 15.09), Ta/Yb (0.25 -0.64), Ce/Pb (mainly 1.62 – 7.88) and high Ba/Nb (19.55 – 314.17, with TA = 1565.00), are similar to those of the continental crust. The rocks are characterised by subduction related Sr/Y content (< 100), except sample MA8 that shows high concentration of Sr/Y (227.71). The magnesian affinity reflects relatively hydrous, oxidizing source which is consistent with origins that are broadly subduction related. Their high – K nature also points to an important petrogenetic role of remelting and differentiation of arc – accretionary complex crust. These geochemical signatures are likely to be related to metasomatism of the sub – continental lithospheric mantle via crustal recycling. In conclusion, the granitoids may have from melting of igneous source in a subduction related environment.
Keywords: Pan-African belt, Dahomeyide, Southeastern Ghana, Ho gneisses, Geochemistry, petrogenesis

1.0 Introduction

The Trans Saharan belt of Africa occurs north and east of the West African craton (WAC) and comprises several Neoproterozoic orogenic belts. Assemblages of ophiolites, accretionary prisms, island-arc magmatic suites and high-pressure metamorphic rocks are clear indications of ocean opening, followed by a subduction or collision related evolution (Kroner and Stern, 2005). The southern portion of the large Trans – Saharan orogenic belt is marked by the Dahomeyide belt that forms southeastern boundary with the WAC; its northern extension being the Iforas in Mali. It is believed to have been formed during the Neoproterozoic Pan African event in the northeast Gondwana assembly (Trompette, 1994). The tectonic setting of this belt has been a subject of debate. Several studies, both petrographically and geochemically have been conducted and different origins have been outlined (Kalsbeek et al., 2010). According to Villeneuve and Cornée, (1994), Trompette, (1997) the belt represents a pre – orogenic rift phase that evolved to an active margin, with subduction and calc – alkaline magmatism occurring between 700 Ma and 600 Ma and final collision against the eastern margin of the WAC at 610–600 Ma, producing granulite – facies metamorphism. Post – collisional plutonism occurred until 500 Ma. For Burke and Dewey (1972), the belt was formed by subduction of oceanic crust and collision of two continental plates. However, for Clifford (1972), the belt represents cratonic chains of reactivated continental basement and supracrustal rock formed during the Neoproterozoic Pan African orogeny. In Mali, it is believed the belt resulted from collision between two continental crusts with west being dioritic accreted crust (Caby and Moussine – Pouchkine, 1978).

Caby (1998) recognized seven tectonic elements that make up the Dahomeyide belt in the southeastern portion of the West African Craton. In southeastern Ghana and adjoining parts of Togo and Benin, the Dahomeyide is a well – organized orogen that is interpreted to have resulted from easterly subduction of the rifted margin of WAC (Affaton et al., 1991; Agbossoumondé et al., 2004; Attoh and Nude, 2008). The

Dahomeyide orogenic terrain is made up of three nappe complexes (Affaton, 1990; Attoh et al., 1997 ; Nude et al., 2012) : the western external units made up of deformed eastern edge of the WAC with its cover rocks (Togo and the Buem structural units), a suture zone assemblage of mafic and ultramafic rocks and the eastern internal units made of granitoid gneiss – migmatite assemblages comprising the Accra and Benin Plains units that underly much of the Benin – Nigerian shield at east of the suture zone (Fig.1) Attoh 1998a. The western external and the eastern internal units may be highly associated with the lower and upper plates respectively in a convergent collisional orogeny (Agbossoumondé et al., 2004). Autochthonous rocks of the deformed edge of WAC are mainly the 2.0 Ga granitoid gneisses which have been transformed into proto – mylonitic gneiss and locally referred to as the Ho gneisses (Attoh 1998a; Attoh et al., 2007; Nude et al., 2009).

Agyei et al. (1987) determined Rb–Sr whole rock isochron ages of 2176 ± 44 Ma (Eburnean age) for the Ho gneiss. The interpretation is that the Ho gneisses may have formed by an extensive ductile shear and are part of the WAC that was reworked during the Pan-African orogeny, and may be time equivalent of the Palimé – Amlamé Pluton (PAP), (Attoh et al., 1997; Hirdes and Davis, 2002; Agbossoumondé et al., 2007), Kara orthogneiss, North Togo (Affaton et al., 1991) or of the Bourré Granite, Mali (La Boisse and Lancelot, 1977; Caby and Moussine - Pouchkine, 1978). This study presents the first time geochemical characteristics of the Ho gneisses. The geochemical features have been compared to reference igneous series through chemical discrimination diagrams in order to define their possible mode of emplacement, origin and tectonic setting.

2.0 Geological Setting

The Pan – African Dahomeyide belt in Ghana occurs at the southeastern corner, roughly that part of a line drawn N – NE from Accra to intersect Ghana – Togo boundary near Agome in the republic of Togo (Kesse, 1985). It is separated from Paleoproterozoic rocks of WAC and rocks of the Voltaian Supergroup by north – south trending, westwards directed frontal thrust. East of the thrust, metamorphic grade and deformation systematically increase eastwards to northwestwards. The western external units of the Dahomeyide belt is made up of deformed eastern edge of the WAC locally known as the Ho gneisses with its cover rocks (Togo and the Buem structural units) deposited on the rift passive margin (Attoh et al., 2013). Bounded to the east of the external zone are the high pressure (HP) mafic rocks forming the suture zone (Attoh, 1998a, Agbossoumondé et al., 2001; Attoh and Morgan, 2004; Nude et al., 2009; Nude et al., 2012) which mark the collisional zone of the WAC and the presumed exotic blocks to the east (Attoh et al., 2013). The eastern internal units are made of granitoid gneiss – migmatite assemblages postulated to include juvenile crust representing an arc terrain that formed during easterly subduction associated with ocean closure (Attoh et al., 2013). According to the earlier workers, (e.g. Agyei et al., 1987[19]) the Ho gneisses are thought to be part of the WAC reworked during the Pan – African orogeny.

3.0 Materials and Methods

3.1 Field Relation

Representative fresh Ho gneisses samples were taken from the deformed eastern margin of the WAC for this study (Fig. 1). Outcrops are mainly biotite gneisses with NE strike and intermediate dip to the east (Fig. 2a). The rocks appear to have experienced deformation. Some (AB2, KL5, TO3, SO5) are light coloured, weakly foliated with head and tail augen structures developed in them (Fig. 2b). This rock suite is well exposed in Ho, Sokode, and Klefe areas; some outcrops characterized by exfoliation surfaces. Outcrops of this rock type were referred to as felsic augen gneiss in the field. In Matse area, outcrops are found in low – lying areas, around Labo River, northeast of Akolikope, northwest of Matse Ando and west of Matse Dzokpe. The rocks observed are brownish grey in colour when fresh and reddish – brown when weathered (Fig. 2b). The rocks are coarse grained and K-feldspar rich granitoid gneiss. The rocks appear to have experienced several episodes of deformation evident by series of crosscutting joints, fractures and faults of varied thickness. The rocks trend NE – SW with SE dip direction. Outcrops observed at Takla area also look a bit different from the other biotite gneisses described above. The rocks are dark coloured and characterized by larger "eye"-shaped crystals of light (quartz and feldspar) and dark (biotite) minerals (Fig.2d). The rocks are weakly foliated but hard due to intense silicification and occur close to the contact between the suture zone mafic granulites and the external nappes rocks. In the field, this type of rocks was referred to as mafic augen gneiss.

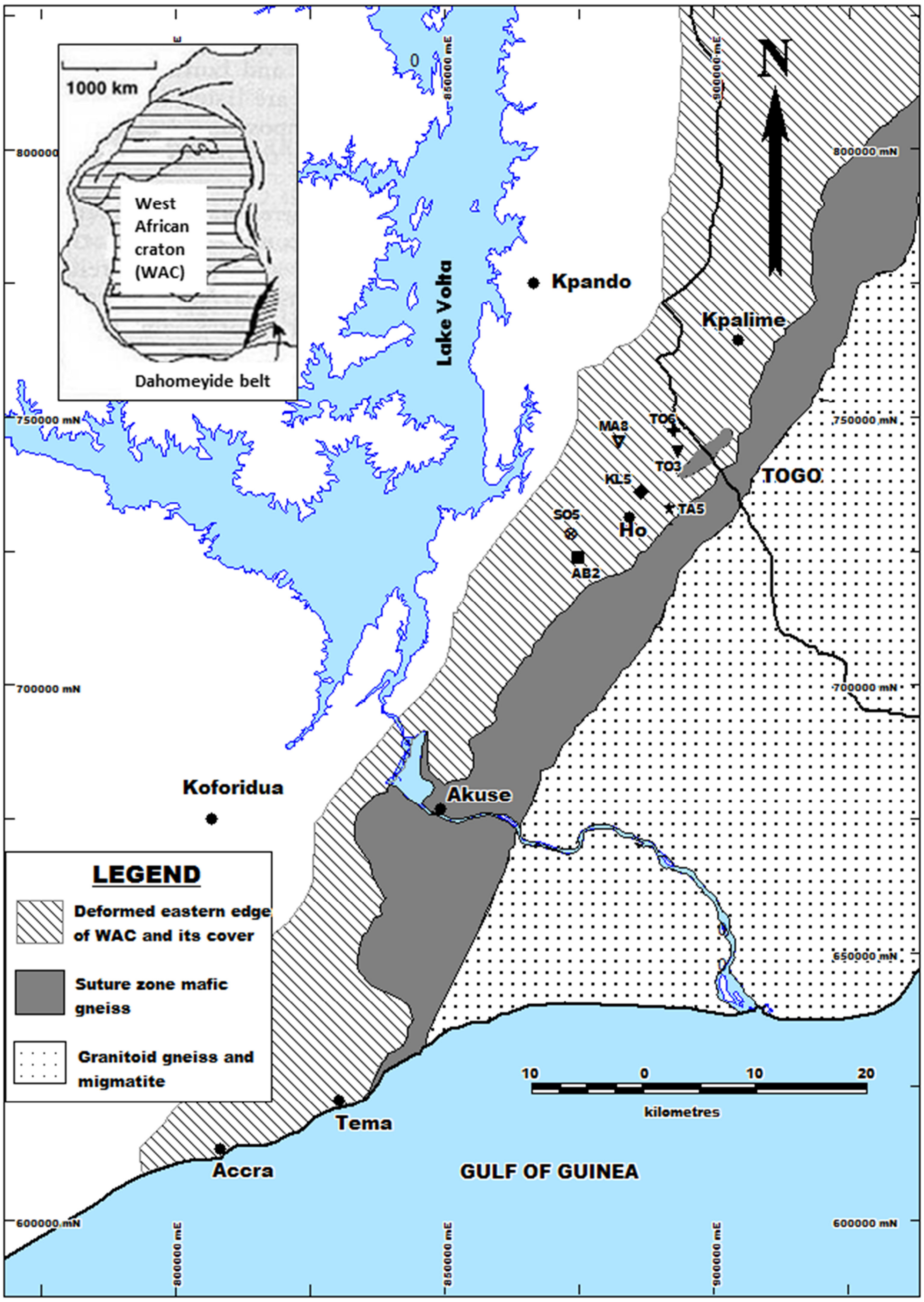

Figure 1. Tectonic map of the Dahomeyide orogen in southeastern Ghana and adjoining part of Togo (After, Attoh, 1998a).

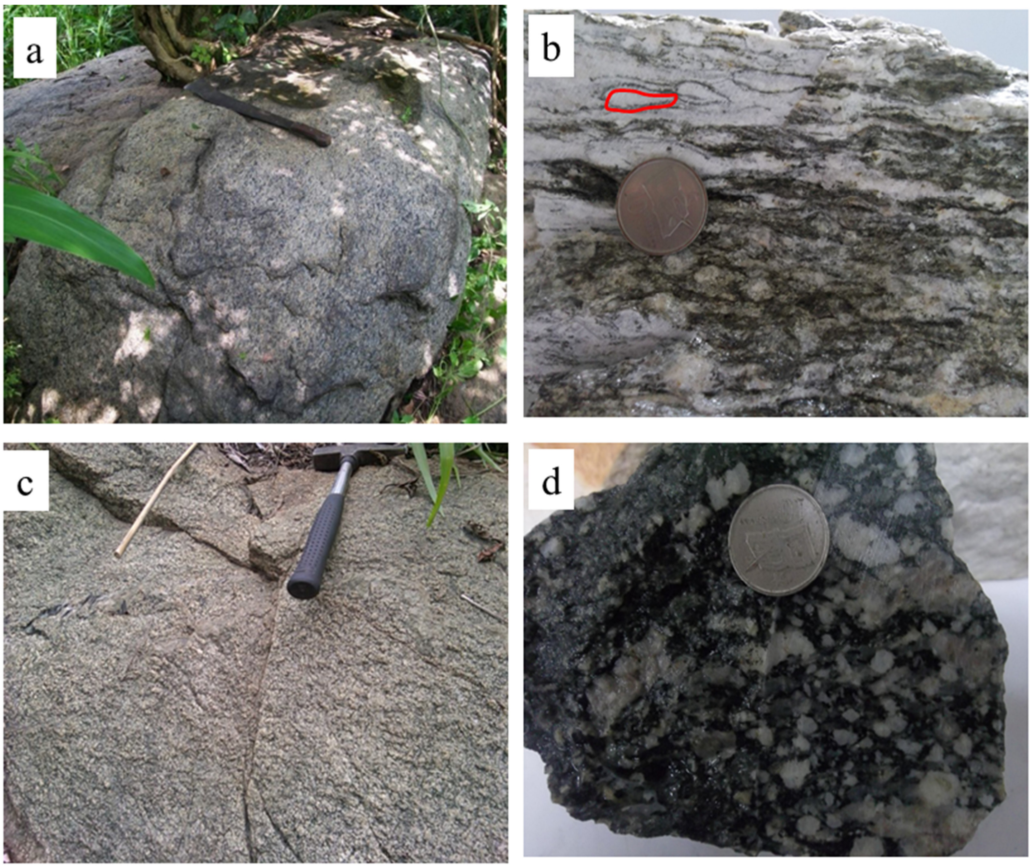

Figure 2. Field photographs of representative samples of the Ho gneiss form SE Ghana. (a) Felsic augen gneiss from Ho area (b) Felsic augen gneiss showing head and tail augen structure (c) Felsic granitic gneiss from Matse (MA8) and (d) Mafic gneiss from Takla area.

3.2 Petrography

Representative rock samples were selected for petrographic studies to determine the textures and mineralogical compositions. The results from the petrography (Table 1) showed that the felsic augen gneiss (AB2, KL5, SO5 and TO3) are composed mainly of quartz (45 – 60 %), plagioclase (15 – 25 %), biotite (10 – 25 %), muscovite (5 – 15 %), sericite (0 – 5 %). The quartz crystals are colourless under plane polarized light and lack cleavages but a few of the minerals show fractures and sutured boundaries. The plagioclase observed is colourless under plane polarized light with mostly subhedral crystal shape. Under cross polarized light, few crystal show weak twining but the majority of them is untwinned. The micas (both biotite and muscovite) are seen to surround the plagioclase (Fig.3a).

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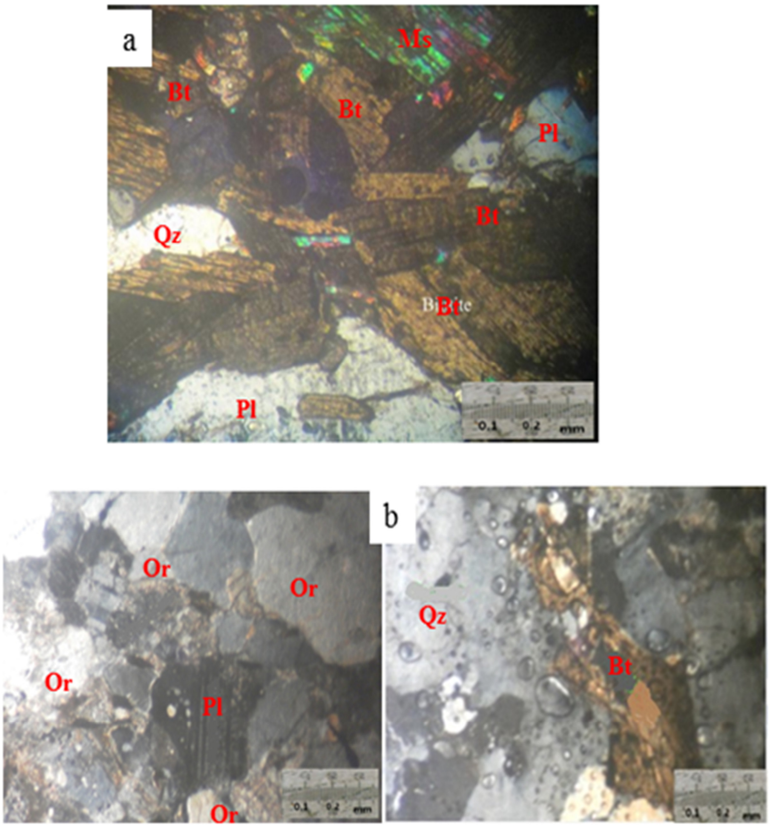

Figure 3. Photomicrographs showing the mineral composition of the Ho gneiss samples (a) Felsic augen gneiss from Ho area (b) Felsic granitic gneiss from Matse. Qz – Quartz, Bt – Biotite, Ms – Muscovite, Pl – Plagioclase, Or – Orthoclase (Adapted after, Kretz, 1983).

The K – feldspar rich granitic gneiss (MA8) is composed of quartz (60%), plagioclase (18%), biotite (10%), K- feldspar (12%) and muscovite (< 1%) (Table 1). Quartz is subhedral with nearly defined boundaries, exhibit sharp undulose extinction with several choncoidal fractures occurring in them. Some of the quartz show iron stains on their surfaces. Plagioclase have irregular and poorly defined outlines with anhedral shapes, and show albite twining and sericitic alterations. The K – feldspars in the have irregular outlines (Fig. 3b). They are anhedral with poorly defined boundaries and exhibit carlsbad twinning. The micas show cleavage in one direction and occur mostly as laths in with muscovite marked by micro – fractures. The mafic augen gneiss (TA5) is composed basically of quartz (30%), plagioclase (25%), biotite (35%) and muscovite (10). The quartz have euhedral to subhedral crystal shapes and are colourless under plane polarized light, with few of the minerals showing fractures and sutured boundaries. Under cross polarized light it shows grey to white interference colours and undoluse extinction. The extinction is not uniform but is shadowy; this shadowy extinction is mainly a characteristic of deformed rocks. Plagioclase is colourless under plane polarized light. Biotite in this rock appears to be high (Bt=35%) and show high pleochroism appearing pale brown under plane polarized light with the usual euhedral shape and perfect cleavages making easy to be split in thin flexible sheets. Both the biotites and muscovites turn to align themselves to define the foliation via physical orientation of the rock. The presences of biotite in all the rock suites reflect the close affinity to hydrous, oxidizing magma source. The detail petrographic results are shown in the table 1.

Table 1. Modal composition of the representative samples of Ho gneisses

Sample ID	Tectonic Unit	Description	Rock name
AB2	Ho gneiss	(Qz = 45) + (Pl = 25) + (B t= 20) + (Ms = 5) + (Ser = 5)	Felsic augen gneiss
KL5	Ho gneiss	(Qz = 45) + (Pl = 15) + (Bt = 25) + (M s= 15)	Felsic augen gneiss
TO3	Ho gneiss	(Qz = 60) + (Pl = 20) + (B t= 10) + (Ms = 5) + (Se r =5)	Felsic augen gneiss
SO5	Ho gneiss	(Qz = 45) + (Pl =25) + (Bt =10) + (Ms =15)	Felsic augen gneiss
TA5	Ho gneiss	(Qz =25) + (Pl=20) + (Bt=45) + (Ms=10)	Mafic augen gneiss
MA8	Ho gneiss	(Qz = 60) + (Pl= 35 + (Bt=30) + (Or=12) + (Ms<1)	K-feldspar rich augen gneiss

3.3 Geochemical Technique

The major and trace element compositions of the representative samples were also determined.. The samples were washed in distilled water followed by ethanol and dried in sun for four days. The dried samples were wrapped in plastic zip lock bags with the sample IDs written boldly on them. The samples were then crushed into smaller fractions of about 30mm in diameter and further into sizes of about 5 mm in diameter. These small splintered rock – chips were finally taken and pulverized into smaller sizes using an agate mortar. The samples were finally sieved using 500µm mesh to obtain powdered samples used for the chemical analyses. The sample preparation was carried out at the GHARR-1 Centre of National Nuclear Research Institute (NNRI), Ghana Atomic Energy Commission (GAEC). Whole rock elements analyses on the selected samples were performed at the ALS laboratory in Vancouver, Canada. The major and trace elements analyses were done using inductively coupled plasma atomic emission spectrometry (ICP-AES) and multi elements fusion inductively coupled plasma mass spectrometry (ICP-MS) respectively. Loss on ignition was determined at 1000 °C. The detail analytical procedures are available at ALS laboratory.

4.0 Results

4.1 Chemical Alteration

Geochemical changes are common phenomenon of granitoids. High loss – on – ignition (LOI) values are mostly the indications of increased dispersion and movement of major and large ion lithophile elements (LILE). Studies have shown that, even for rocks of prehistoric inheritance, the concentrations of such 'mobile' elements do not significantly change from their background abundances (e.g. Whalen et al., 1999). Due to the relatively immobile nature of high field strength (HFSE) and rare earth elements (REEs) under most conditions (e.g., Pearce and Cann, 1973; Whalen et al., 1999), they have often been used for igneous petrogenetic and tectonic studies. On the other hand, due to high susceptibility to mobility during processes such as metamorphism and hydrothermal activities, major elements have mostly been used to give background information. However, if the dispersion of the major elements is minor, they could still reveal the principal igneous processes involved in the formation of the rocks. Nevertheless, the extent to which the Dahomeyide granitoid gneisses had been altered was investigated using the chemical index of alteration (CIA) calculations of Nesbitt and Young (1982). According to Nesbitt and Young (1982), CIA value of any rock above 60 indicates alteration. The CIA values for the Ho gneiss samples ranges between 53 and 62 (Table 2) which indicates that the rocks have not gone through much alteration.

Table 2. Major elements composition of the Ho gneisses (wt. %)

SAMPLE	AB 2 ME-ICP06	KL 5 ME-ICP06	SO 5 ME-ICP06	TO 3 ME-ICP06	MA 8 ME-ICP06	TA 5 ME-ICP06
SiO_2	63.40	56.00	67.50	68.80	68.90	56.10
Al_2O_3	14.15	16.30	12.85	15.30	14.35	13.90
Fe_2O_3	5.10	8.12	4.95	3.42	2.94	11.70
CaO	3.00	4.85	2.06	2.54	2.66	8.70
MgO	1.54	3.09	1.54	0.98	0.94	4.85
Na_2O	2.82	3.71	2.43	3.55	3.00	2.69
K_2O	3.12	3.21	4.19	3.69	2.88	0.70
Cr_2O_3	0.02	0.02	0.02	0.02	0.01	0.03
TiO_2	0.82	1.26	0.81	0.54	0.46	0.69
MnO	0.05	0.10	0.04	0.03	0.02	0.12
P_2O_5	0.31	0.51	0.33	0.23	0.30	0.09
SrO	0.09	0.10	0.06	0.07	0.08	0.03
BaO	0.20	0.21	0.22	0.20	0.32	0.05
Total	96.14	98.81	98.89	100.23	98.86	100.51
LOI	1.52	1.33	1.89	0.86	2.00	0.86
FeO_t	4.59	7.31	4.45	3.08	2.65	10.53
Mg#	37.42	42.98	38.12	36.20	38.77	45.08
MALI	2.94	2.07	4.56	4.70	3.22	-5.31
F*	0.75	0.70	0.67	0.94	0.74	0.68
A/CNK	1.05	0.89	1.05	1.06	1.11	0.66
A/NK	1.77	1.70	1.51	1.56	1.78	2.68
ASI	1.08	0.92	1.08	1.08	1.14	0.67
CIA	61.28	58.07	59.68	61.00	62.69	53.48
		CIPW Norm (Vol. %)				
Q	6.90	25.86	31.41	33.39	8.05	12.23
C	0.00	1.42	1.36	2.18	0.00	0.00
Or	18.97	18.44	24.76	17.02	1.95	4.14
Ab	31.39	23.86	20.56	25.39	32.83	22.76
An	18.34	12.86	8.06	11.24	17.35	23.79
Ne	0.00	0.00	0.00	0.00	0.00	0.00
Di	1.95	0.00	0.00	0.00	13.52	15.38
Hy	11.57	6.79	4.14	4.06	5.39	13.30
Ol	0.00	0.00	0.00	0.00	0.00	0.00
Mt	11.77	7.40	7.18	4.26	7.89	16.96
Il	2.39	1.56	1.54	0.87	4.66	1.31
Hm	0.00	0.00	0.00	0.00	11.06	0.00
Ap	1.21	0.73	0.78	0.71	0.83	0.21

4.2 Major Elements

Despite lithological differences observed among the samples, all the analyzed granitoid gneiss (Ho gneiss) samples from the Dahomeyide belt SE Ghana show similar major elements composition. Thirteen major elements were determined on the Ho gneisses (Table 2). The concentration of SiO_2 ranges between 56.00 and 68.90 wt. %. The rocks have high Al_2O_3 content of 12.85 – 16.30 wt. %; TiO_2 of 0.46 – 1.26 wt. % and wide range of FeO_t values (2.65 to 14.85wt. %). The rocks are composed also of MnO 0.02 – 0.12 wt.%; MgO of 0.94 – 4.85 wt.%; CaO of 2.06 – 8.70 wt.%; Na_2O of 2.43 – 3.71 wt.%; and K_2O of 0.70 – 4.19wt.%). The CaO, MgO, TiO_2, and FeO_t contents apparently decrease with increasing SiO_2 content, whereas Al_2O_3 and Na_2O increase with SiO_2 (Fig. 4). Harkar plots of SiO2 against some selected trace elements (not shown) show decrease in Y, Ni, V, Nb and increase in Sr and Ba with increasing SiO2 content.

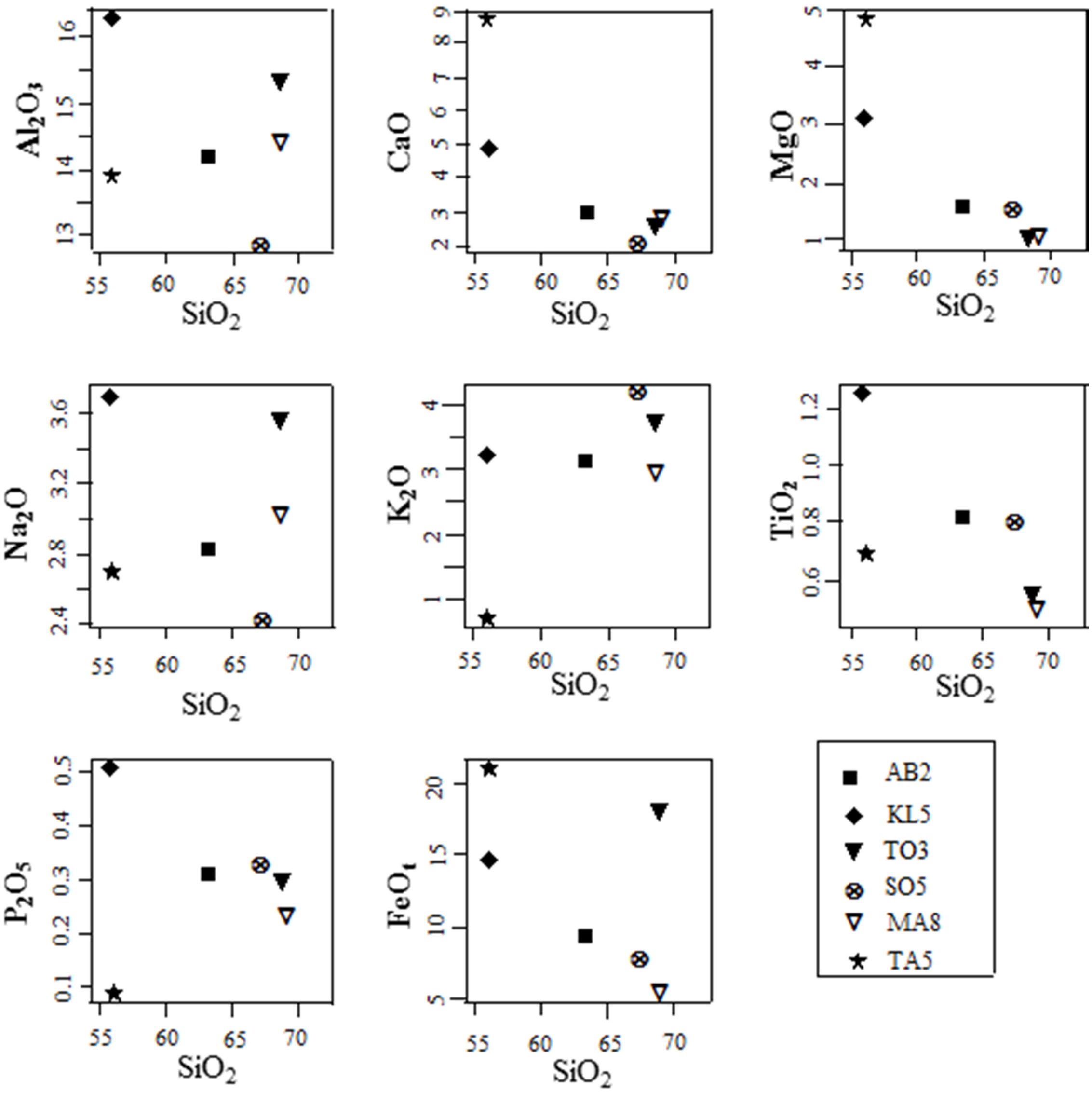

Figure 4. Plots of SiO_2 versus the other major elements (wt. %).

The overall decreasing trends of FeO_t, MgO, Y, Ni, Nb suggest fractionation of mafic minerals. The rocks contain high K_2O content (> 2.0) with TA5 showing relatively low K_2O content (< 1) and K/N values of < 1 except sample SO5 that has K/N value of 1.13. The total alkalis A/NK [molar (Al_2O_3/ Na_2O+K_2O)] and A/CNK [molar (Al_2O_3/ CaO+Na_2O+K_2O)] contents range from 1.51–2.68 and 0.66–1.14 respectively (Table 2). The alumina saturation index [ASI= molar [Al/ (Ca – 1.67P + Na + K]] contents also range from 0.67–1.14 which is typical I-type signature. The rocks have relatively high magnesium number (Mg#: 36 – 46) and iron number (Fe*) between 0.67 – 0.94. These characteristics are typical for both ferroan and magnessian rich rocks. Cross – Iddings – Pirsson –Washington (CIPW) norm calculations were performed for all the rocks using ferric – ferrous iron ratio of 0.15 to mollify any effect that might have resulted from post – emplacement oxidation processes. The results show that all the granitoid gneisses are quartz – normative (6.90 – 33.39). They contain normative hypersthene in the range of 4.06 – 13.30, anorthite in the range of 8.06 – 23.79 but none of the samples contain normative olivine. The detail major elements composition and the normative mineral assemblages are presented in table 2 above.

4.3 Trace and Rare Earth Elements

The REEs and trace elements data on the Ho gneisses show related characteristics. The REE patterns of the Ho gneisses show enrichments in LREE relative to the HREE (Table 3). On the chondrite normalized rare earth elements (REEs) variation diagram (Fig. 5), the rocks display fractionated patterns with an overall negative slope. They are characterised by decreasing abundance from LREEs to HREEs with noticeable negative Tm and slightly negative Eu anomalies (Eu/Eu* = 0.68 - 0.94). (AB2, KL5, SO5, TA5) with samples TO3 and MA8 portraying positive Eu anomaly (Eu/Eu* =1.19 and 2.10 respectively). The rocks show highly fractionated

$(La/Yb)_N$, $(La/Lu)_N$ and Ce/Yb_N contents of 16.87 - 76. 33, 16.59 – 64.90 and 2.24 – 31.94 respectively. The rocks have, Ce/Sm_N and $(La/Sm)_N$ contents of, 1.11 – 2.37 and 2.70 – 7.79. Samples TA5 and AB2 show varying characteristics of REEs. AB2 shows negative Yb anomaly and extremely high $(La/Yb)_N$ and Ce/Yb_N contents of 5369.00 and 3889.00 whereas the TA5 shows very low (La/Lu)N and $(La/Yb)_N$ contents of 3.71 and 4.19 respectively (Fig.5 and Table 2).

In the incompatible trace-element concentrations normalized to the primitive mantle using Sun and McDonough (1989) normalized values (Fig. 6), the Ho gneisses display nearly linear distribution characterised by decreasing abundance from large ion lithophile elements (LILE) down to high field strength elements (HFSE). Samples AB2, KL5, SO5, and TO3 show gentle slope pattern with noticeable positive Rb, Ba, K, Pb and slightly Pr-Hf enrichment and are depleted in Cs, Th, U, Ta, Nb, Ti with slightly negative Eu anomaly except TO 3 that shows slightly positive Eu anomaly. MA8 show enrichment in Ba, K, Pb, Sr, Zr, Hf, Eu, Lu and negative Cs, Th, U, Ta, Nb and Tm anomaly. TA5 is characterised by negative Cs, Rb, K, Ta, Nb, Sr, Th, Zr, Hf, Ti, and Tm and are enriched in Ba, U and Pb. The marked depletion in Nb and Sr content characterize them as typical crustal derived magmas (Deniel et al., 1987).

The trace elements characteristics give indication of varying sources for the Ho gneisses but, the depletion in Nb, Ta, and Ti and rich in Ba, K, especially Pb, are typical signatures of ''arc rocks'' or continental crustal materials (i.e., the familiar ''arc signature'' or ''crustal signature''). Lavecchia et al. (2006) suggested this distribution requires a high oxygen (O_2) fugacity in the source region to allow HFSE fractionation which could also produce the Eu anomaly. While this interpretation may be possible, the negative Eu anomaly is more likely a source inheritance (Guo et al., 2013). Their incompatible trace element ratios, such as Th/U (1.07 – 13.87), K/Rb (272 – 574.47), Th/Yb (0.79 – 15.09), Ta/Yb (0.25 -0.64), Ce/Pb (mainly 1.62 – 7.88) and high Ba/Nb (19.55 – 314.17, with TA = 1565.00), are similar to those of the continental crust (Rudnick and Fountain, 1995; Rudnick and Gao, 2003), and resemble the values recorded by magmas that formed in active continental margins (Wilson, 1989).

On the other hand, the Eu anomalies may be attributed to the varying concentration of plagioclase minerals observed among the samples which is typical of processes in crustal magma chambers and matches field and petrographic evidence of the abundance of plagioclase phenocrysts. The rocks are characterised by subduction related Sr/Y content (< 100), except sample MA8 that showing high concentration of Sr/Y (227.71). Taking into account these data, the involvement of a crustal - derived or subduction – modified component in mantle sources is apparent.

Table 3. REEs and Trace elements composition (ppm) of the Ho gneisses

SAMPLE	AB 2	KL 5	TO 3	SO 5	MA 8	TA 5
	ME-MS81	ME-MS81	ME-MS81	ME-MS81	ME-MS81	ME-MS81
Ce	95.20	37.50	94.60	34.10	107.00	27.10
Cs	0.14	0.33	1.26	0.04	0.32	0.12
Rb	69.90	68.80	97.50	4.70	116.00	71.20
Ba	1885.00	798.00	1890.00	258.00	1930.00	3130.00
Th	1.82	1.65	3.85	2.73	8.60	0.44
U	0.48	0.40	1.01	0.46	0.62	0.41
K	25900.00	21500.00	26600.00	2700.00	34800.00	24000.00
Ta	0.20	0.70	0.90	0.80	0.30	0.10
Nb	6.00	9.70	14.60	13.20	7.80	2.00
La	50.90	18.00	44.90	14.40	60.60	16.30
Pb	12.00	12.00	12.00	21.00	15.00	6.00
Pr	12.50	4.94	14.00	5.12	14.40	3.23
Sr	764.00	327.00	856.00	141.00	519.00	797.00
Nd	48.10	19.80	58.50	21.30	51.00	11.90
Zr	333.00	226.00	502.00	220.00	304.00	236.00
Hf	8.80	6.40	12.70	5.80	8.10	6.10
Sm	6.96	3.82	10.75	5.15	6.91	1.80
Eu	1.65	1.37	2.51	1.74	1.70	1.05
Ti	4920.00	4680.00	7600.00	14700.00	4860.00	3240.00
Gd	4.81	3.85	8.67	6.08	4.45	1.30
Tb	1.82	1.65	3.85	2.73	8.60	0.44
Dy	2.42	3.57	5.34	6.55	2.24	0.71
Y	10.60	19.90	25.30	35.30	10.50	3.50
Ho	0.42	0.75	0.95	1.40	0.40	0.12
Er	0.97	2.15	2.39	3.77	0.89	0.32
Tm	0.09	0.30	0.32	0.44	0.09	0.01
Yb	0.63	2.09	1.91	3.17	0.57	0.25
Lu	0.11	0.35	0.29	0.55	0.10	0.05
Sr/Y	72.08	33.83	95.91	49.43	227.71	6.86
Th/U	3.79	4.13	3.81	5.93	13.87	1.07
K/Rb	370.53	312.50	272.82	574.47	300.00	337.08
K/N	0.73	0.57	0.68	1.13	0.63	0.17
Ba/Nb	314.17	82.27	129.45	19.55	247.44	1565.00
Th/Yb	2.89	0.79	2.02	0.86	15.09	1.76
Ta/Yb	0.32	0.33	0.47	0.25	0.53	0.40
Ce/Pb	7.93	3.13	7.88	1.62	7.13	4.52
Eu/Eu*	0.87	0.79	1.19	0.94	2.10	0.68
$(La/Lu)_N$	49.60	16.59	56.38	64.90	34.91	3.71
$(La/Sm)_N$	4.72	2.70	7.79	5.66	5.85	2.06
$(Ce/Sm)_N$	3.42	2.20	5.38	3.87	3.77	1.81
$(La/Yb)_N$	5369.00	16.87	72.31	76.33	46.79	4.19
$(Gd/Yb)_N$	585.25	3.76	4.55	6.46	4.30	1.72
Ce/Yb_N	2380.00	8.42	30.58	31.94	18.44	2.24
Ce/Sm_N	2.09	1.35	3.29	2.37	2.30	1.11

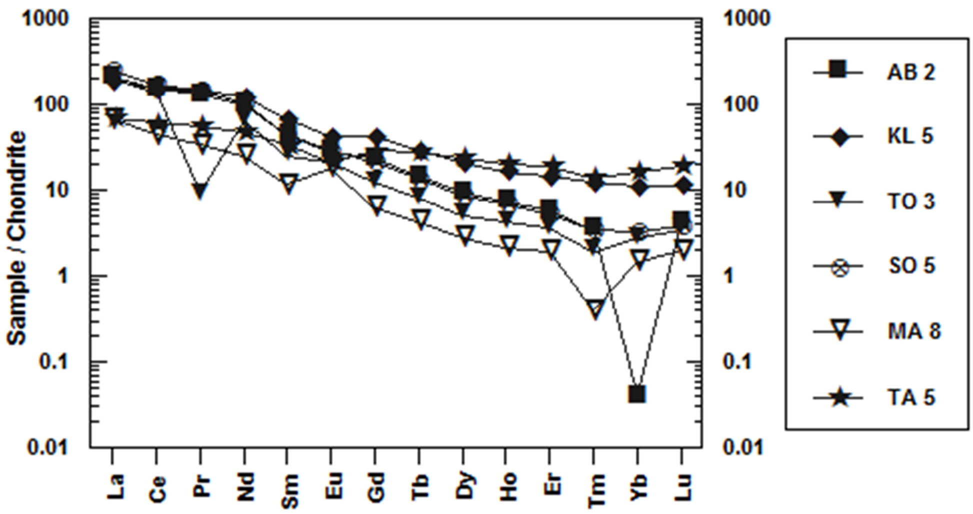

Figure 5. Chondrite normalized REEs distribution pattern of the studied granitoid (Ho gneiss) samples (after Sun and Mc Donough 1989).

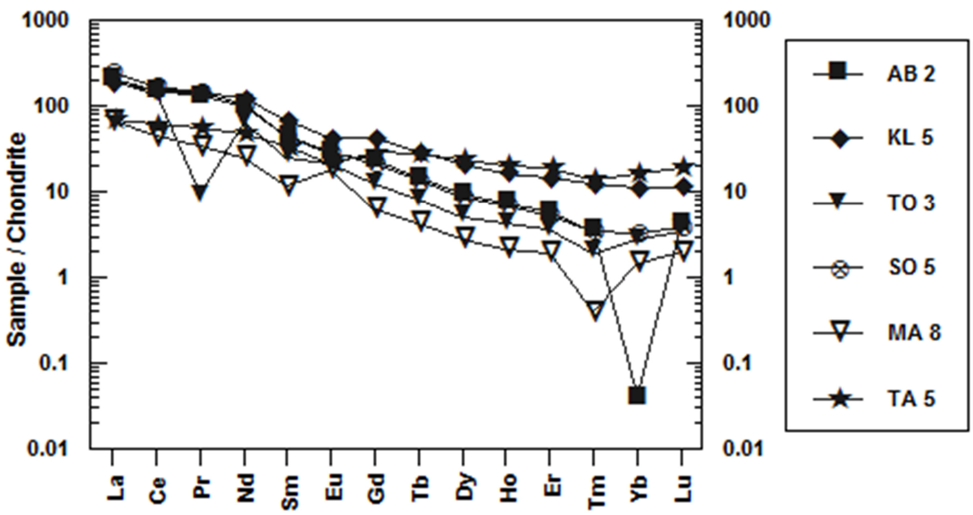

Figure 6. Primitive mantle normalized trace elements distribution pattern of the studied granitoid (Ho gneiss) samples (after Sun and Mc Donough 1989).

5.0 Discussion

5.1 Classification

Several classification schemes, which involve parameters such as presumed origin of granitoids, geochemistry, and tectonic setting, have been proposed for the classification of granitoids (Frost et al., 2001). In this study, the Ho gneiss rocks have been classified in selected geochemical schemes. The classification of rocks, based on normative Ab – An – Or scheme (O'Connor, 1965; Barker, 1979), are shown in Figure 7. The rocks plot mainly in the field of granodiorite, close to the boundary with quartz – monzonite, with samples MA8 and TA5 plotting in the quartz – monzonite and tonalite fields respectively. On the classification scheme of Frost et al. (2001), the Ho gneisses display magnesian to ferroan characteristics (Fig. 8a), mainly calc – alkalic with few showing calcic (TA5) and alkali – calcic affinities (KL5) (Fig. 8b). They are metaluminous to weak peraluminous reflecting the presence of biotite and muscovite, but I - type in nature (Fig. 8c). These characteristics together with the positions of the samples on the A/CNK-A/NK diagram (Shand, 1943; Maniar and Piccoli 1989) further support I – type affinity for the Ho gneiss (Fig. 9). On the classification plot of SiO_2 versus K_2O of Peccerillo and Taylor, (1976) (Fig. 10), the rocks plot mainly in the field of high – K series field and TA5 plotting in the field of medium – K, close to the boundary with low K series. All these characteristics give an indication of varying source of the Ho gneiss rocks.

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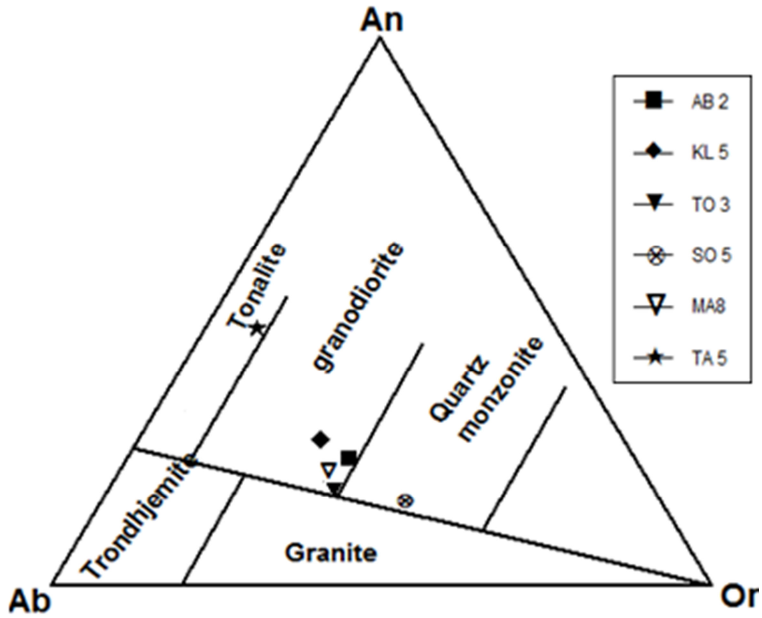

Figure 7: A ternary plot Ab-An-Or of the studied samples (after O'Connor, 1965).

5.2 Petrogenesis

The origin and the magmatic suite of the Ho gneiss from the Dahomeyide belt, Southeastern Ghana have been evaluated using the major and trace elements compositions. The major element compositions of the samples reveal an evolutionary trend for the rocks. The CaO, MgO, TiO_2, and FeO_t contents apparently decrease with increasing SiO_2 content, whereas Al_2O_3, K_2O and Na_2O increase with SiO_2 (Fig. 4). Harkar plots of SiO_2 against some selected trace elements (not shown) show decrease in Y, Ni, V, Nb and increase in Sr and Ba with increasing SiO_2 content. The apparent negative correlation between SiO_2 and FeO_t, MgO, CaO, Y, Ni, and Nb contents in the rocks indicate fractional crystallization involving the assemblage plagioclase and biotite which is in good agreement with the field and petrographic evidence of the abundance of plagioclase phenocrysts and biotite. The abundance of hydrated minerals (e.g. biotite) in the plutonic rocks suggests that the melting of the protolith took place under hydrous conditions. The mostly granodioritic with few tonalitic and quartz - monzonitic features observed (Fig. 7), the high Na_2O and K_2O contents (Table 2) together with their affinity for calc – alkalic with a few plotting in the calcic and alkalic – calcic fields (Fig. 8b) may be compared to the Achaean TTG suites (Frost et al., 2001). They have comparable Sr/Y (< 100) ratio with relatively low Y contents which are characteristics of transitional composition between TTGs and an arc rocks (Defant and Drummond, 1990; Agbossomoundè et al., 2007). It is noted however that, Archaean TTGs complexes are characterised by subduction signatures coupled with steep rare earth profiles (LILE enrichment) and hence may originate by fusion of basalt in a subduction setting (Rapp et al., 1991).

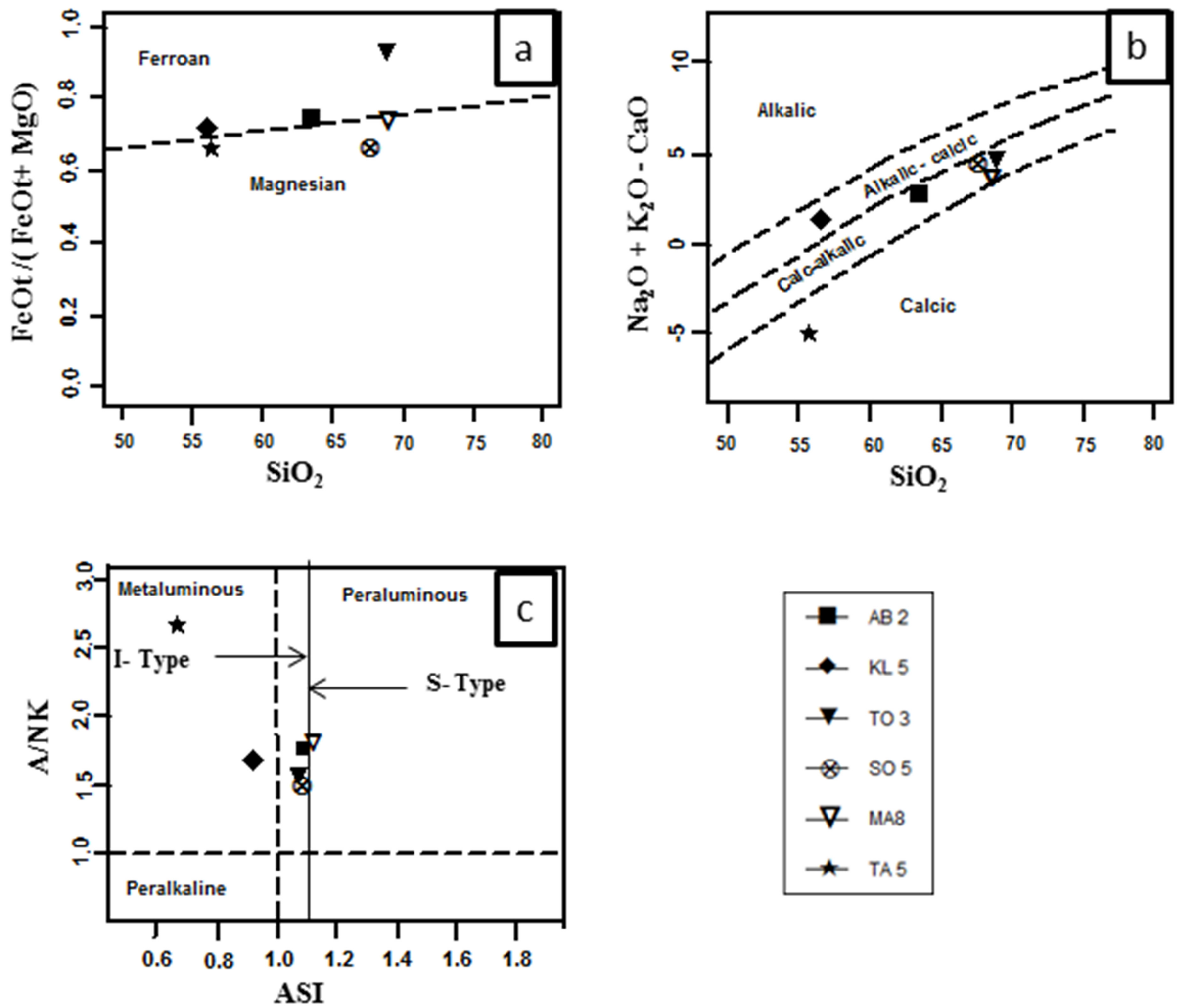

Figure 8: Binary plot for classification of the granitoid gneiss from Dahomeyide orogenic belt (after Frost et al. 2001). (a) SiO_2 versus FeO_t/ (FeOt MgO) (b) SiO_2 versus (Na_2O+K_2O-CaO) (c) ASI versus A/NK (after Frost et al. 2001).

The geochemical differences between the samples may also support the idea of crystal fractionation probably, during the ascent of the melts from the lower crust where they were generated up to the upper crust where they finally solidified. Frost et al. (2001) observed from MALI diagram that most granitoids follow sub – parallel alkali – lime trends during differentiation. Hence, any observed crossing of trend divides or lines by a granitoid suite may indicate mixed magma sources or extreme differentiation of the parent magma for the rocks. On the Frost et al. (2001) diagrams, the Ho gneisses show magnesian to ferroan, calcic to alkali calcic (Fig. 8a – b), metaluminous to weakly peraluminous with I – type imprints (Fig.8c and 9). Iron enriched melts derived from reduced basaltic sources (either tholeiitic or mildly alkalis) make important contribution to ferroan granitoids and reflects a close affinity to relatively anyhydrous, reduced magmas and source regions (Frost and Frost, 1997). According to the latter authors, because these magmas are hotter, they are likely to undergo extensive fractionation towards iron rich alkali compositions; magnesian rocks in contrast are probably related magmas which follow relatively oxidizing differentiation trends.

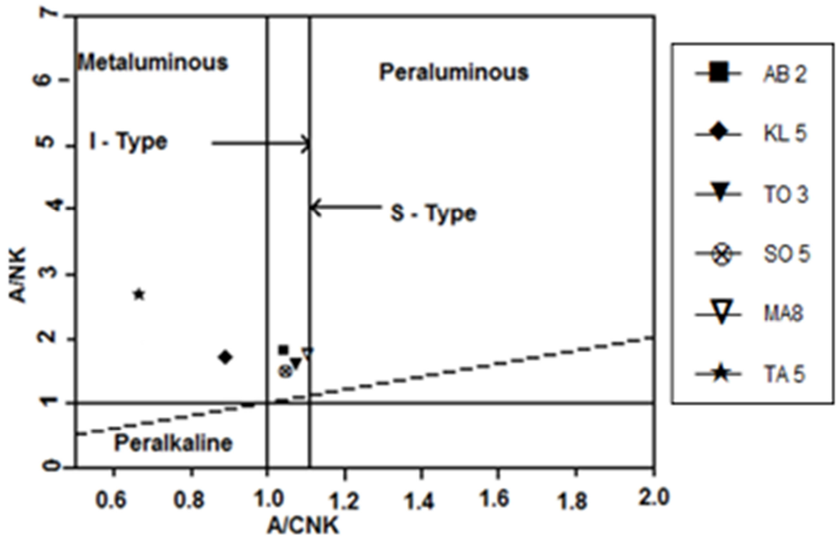

Figure 9: Geochemical plot of (a) A/CNK versus A/NK (after Shand, 1943 Maniar and Picolli 1989).

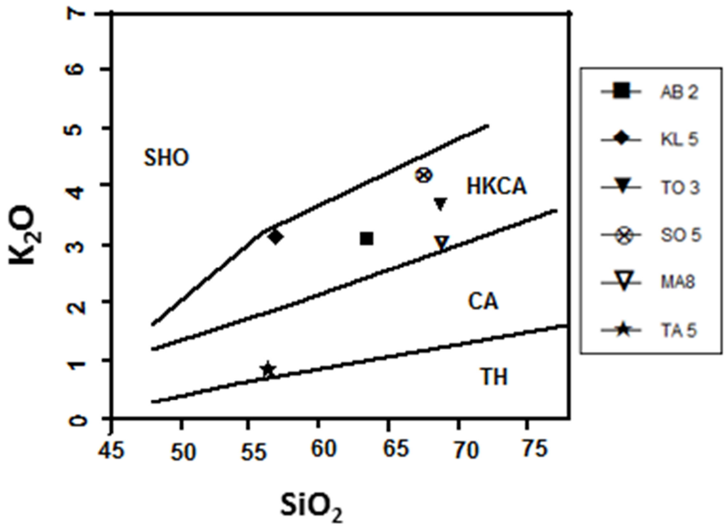

Figure 10: Classification plot of SiO_2 versus K_2O (after Peccerillo and Taylor, 1974; Rickwood, 1989). SHO – Shoshonite series, HKCA – High-K Calc-alkaline, CA – Calc Alkaline, TH – Tholeiite series.

A secondary effect on Fe* which seem particularly at high silica contents is the composition of the crustal melt with wide range of Fe* may be explanation for the population of ferroan granitoids and magnesian nature may be source inheritance. However, according to Chappell and White (1974), I – type granitoids, metaluminous to weak peraluminous, relatively sodic, with wide range of silica contents are formed from mafic meta – igneous source, possibly by partial melting of continental crust. The studied rocks show elevated concentration of K with $K_2O > 1$ and plot in the High – K fields, except TA5 that has $K_2O<1$ and also plot in the medium – K field. Their High – K to medium – K and metaluminous to weakly peraluminous character requires a metaluminous and high – medium – K source material or protoliths. The geochemical features of high – K granitoids are supportive of origin in relation to a convergent margin setting, pointing to an important petrogenetic role of remelting and differentiation of arc – accretionary complex crust. Although there are some controversies, it is generally accepted that water plays a major role in producing high – K, I – type, calc – alkalic magmas Murphy (2007).

Several experimental studies (e.g. Sisson and Grove 1993; Grove et al. 2003) suggest that calc – alkalic magmas form by hydrous melting of the mantle, and then rise to the shallow crust where they undergo fractional crystallization under near - H2O saturated conditions. Proposed mechanisms of formation begin with partial melting of subducted material and of mantle peridotite altered by water and melts derived from subducted material. The LREE– enriched patterns with mostly negative Eu anomalies together with the high – K imprints are typical of many subduction related magmas from island arcs or active continental margins (Kumar and

Sreejith, 2011). This is well in line with distinctive features of convergent plate margin magmatism, resulting from melting of igneous source in a subduction related environment (Kumar and Sreejith, 2011). Even though the nature of this component may be unclear, but the main inference from this study is the involvement of a recycled component into the mantle, which might be associated with lower crustal material and that is why the rocks show trace element ration consistent with the continental crust (Table 3). Many of these granitoids at the western side of the Pan-African mobile belt in Ghana, Togo and Bénin have been associated with Paleoproterozoic age (Agbossoumondé et al., 2007).

In relation to the Pan African orogenic zonation (Caby, 1989; Affaton et al., 199) these granitoids belong either to the active margin i.e. the Bénin – Nigerian shield or to the passive margin, i.e. the West African Craton. According to Agbossoumondé et al., (2007), many Paleoproterozoic granitoids appear as klippens and inliers on the western side of the main Pan-African suture and consist of basement nappes closely associated with Pan-African metasedimentary rocks and mafic to ultramafic meta-igneous rocks. The indication that the WAC would be associated with the incorporation of continental crustal rocks into the mantle further supports our proposals involving either continental subduction or delamination.

5.3 Tectonic Setting

Several schemes exist for assigning granitoids to various tectonic environments by means of their geochemical characteristics (e.g., Pearce et al., 1984; Maniar and Piccoli, 1989; Pearce, 1996a). Trace elements have been paramount in such schemes. However, few of the major-element schemes have been useful in discriminating between the granitoids that belong to different tectonic environments. The nearly linear negative slope pattern with enrichment in LREEs and LILE (Rb, Ba, K, Pb, Sr-Hf) and depleted in HFSE with negative Ta, Nb, Ti are typical arc roots together with the enrichment in LREES and LILE with negative Sr, Zr, K, Hf, Nb and Ti also observed in TA5 (Fig. 5 and 6) together with the ferroan to magnesian, and calcic to alkali calcic characteristics may also testify magmatic activity involving mixing sources. Ferroan granitoids reflect a close affinity to relatively anyhydrous, reduced magmas and source regions. Such are conditions are common in extensional environment (Frost and Lindsley, 1991; Frost et al., 2001). Magnesian series reflect close affinity to relatively hydrous, oxidizing magmas and sources region which is consistent with origins that are broadly subduction related (Frost and Lindsley, 1991; Frost et al., 2001). These give indication of mixing tectonic setting but, as already discussed, a secondary effect on Fe* which seem particularly at high silica contents is the composition of the crustal melt with wide range of Fe* may be explanation for the population of ferroan granitoids at high silica content (Frost et al., 2001). The primitive mantle – normalized multi-element plots (Fig. 6) of these rocks show elevated concentration of LILE with typical arc like signatures (deep Nb, Ta and Ti troughs together with large positive Pb anomalies) Orejana et al. (2009). The enhanced level of LILE relative to HFSE in the Ho gneisses points to the subduction – zone enrichment and/or crustal contamination of the source region (Arvin and Rotstamizadeh, 2000). Such crustal influence is also reflected in the incompatible trace element ratios and major element as explained above. According to Kumar and Sreejith (2011), the LREE – enriched patterns with negative Eu anomalies together with high – K signatures are also typical of many subduction related magmas from island arcs or active continental margins.

Accordingly, in order to infer the geotectonic environment of emplacement of the Ho gneiss, we have used various tectonic discrimination diagrams. The rocks show subduction related signatures with Sr/Y<100 (Huang et al., 2010) except MA8 and plot in the field of Sr/Y vs Y consistent with subduction components (Fig. 11a). On the R1-R2 diagram Batchelor and Bowden, (1985), all the samples plot in the field 6 (syn –collisional) with only one sample (TA5) plotting in the field of pre – collision granites field (2). Syn collisional is synonymous to the volcanic arc granite (VAG) in the scheme of Pearce et al. (1984) and Pearce (1996a). Syn – collision settings are linked to the process of crustal thickening, usually by the underthrusting of one crustal 'slice' beneath another (Batchelor and Bowden 1985), which was founded in the chemical classification scheme of De La Roche et al. (1980). Syn-collision granites linked to continent – arc collision are the last intrusions in the life – cycle of a volcanic arc where they form metaluminous, I – type granites with biotite as one of most common ferromagnesian minerals. For comparison, reference samples such as volcanic arc granite (VAG) from Chile and within plate granite (WPG) from Oslo are plotted together with the samples. All the granitoid gneisses follow similar trend as the VAG with positive Rb, Ba, Th Ce and negative Ta, Nb, and Yb (Fig.12).

The trace elements tectonic discriminant plots of Y+Nb versus Rb, Y versus Nb, Ta+Yb versus Rb and Yb versus Ta (Fig. 13) also suggest volcanic arc roots for the granitoids and are plotted in the volcanic arc granitoids (VAG) field Pearce et al. (1984). Volcanic arc granites (VAG) form discrete, often zoned plutons in island arc terranes and linear, composite batholiths at active continental margins. They commonly form I-type granodiorite and tonalite intrusions which are metaluminous, calc – alkaline, with biotite as common ferromagnesian minerals have standard subduction signatures with enrichment in LIL elements relative to HFS (high field strength) elements (Pearce, 1996a).

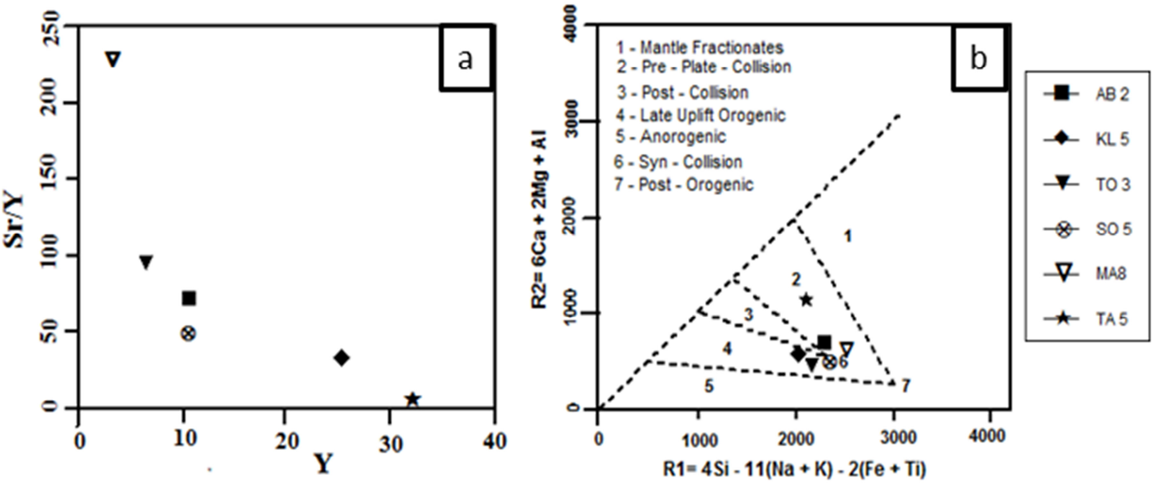

Figure 11: Plot of (a) Y versus Sr/Y (b) R1 versus R2 (after, Batchelor and Bowden, 1985).

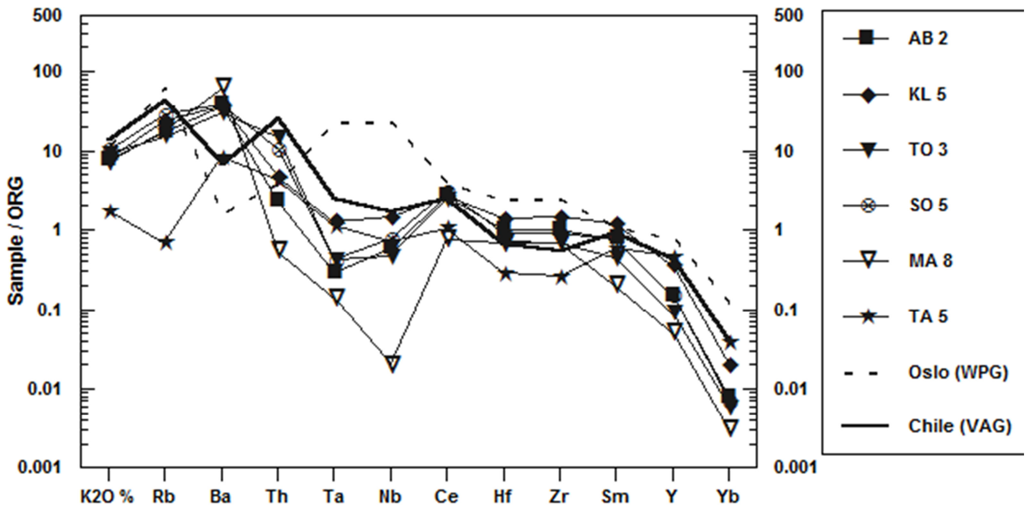

Figure 12: ORG-normalized diagram of granitoid gneisses from Dahomeyide belt of Ghana (after Pearce et al., 1984).

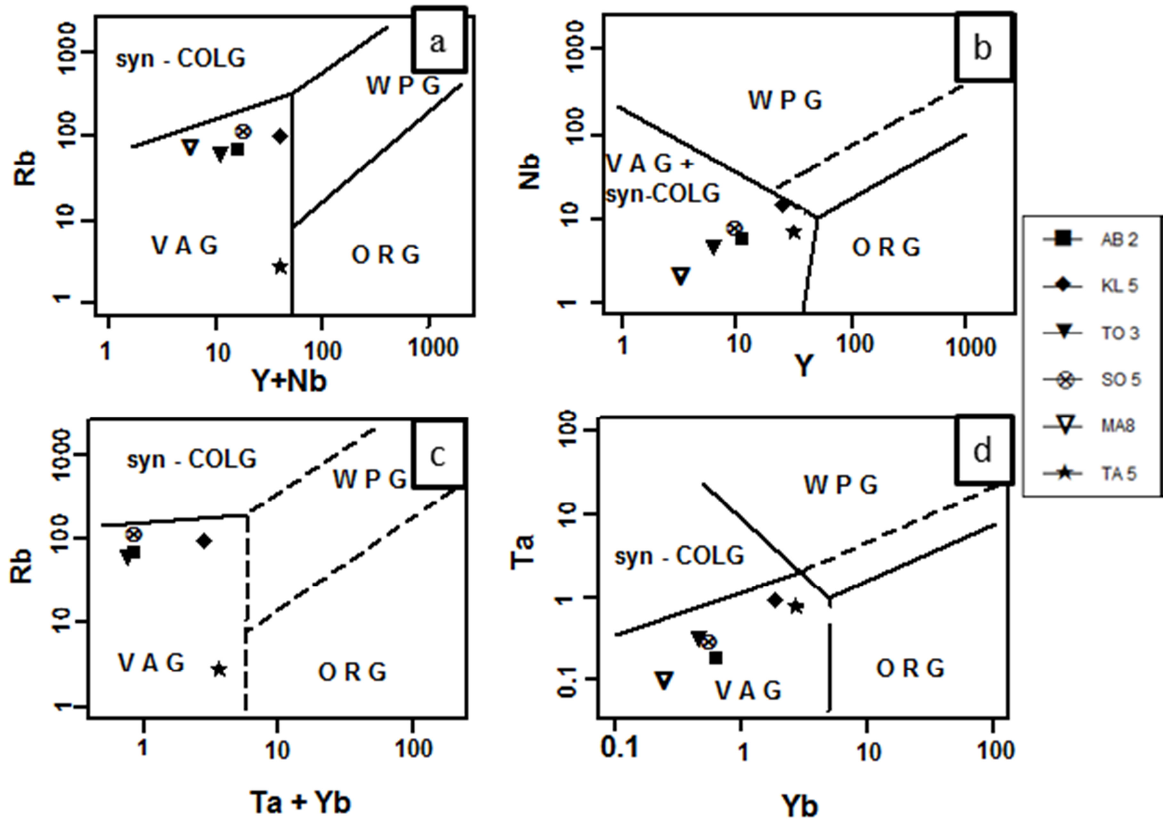

Figure 13: Trace elements ratio plots for tectonic classification of the granitoids from Dahomeyide orogenic belt (i) Y + Nb versus Rb (ii) Y versus Nb (iii) Ta + Yb versus Rb (iv) Yb versus Ta (After Pearce, 1996a).

However, the high K_2O contents of the Ho gneiss rocks reveal their high – K nature. As well as having enhanced K contents as a result of high K_2O contents of the Ho gneiss, their enrichment in other incompatible elements reflects the importance of crustal rocks in the magma source (s) (Roberts et al., 1993; Arvin and Rotstamizadeh, 2000). Such an enrichment event accounts for the arc – like signatures of this mantle - derived rocks and explains the addition of volatiles to the mantle source. This geochemical signature is likely to be related to metasomatism of the sub – continental lithospheric mantle via crustal recycling. Taking into account these data, the involvement of a crustal – derived or subduction – modified component in the mantle sources is apparent. The crustal component may have derived from partial melting of rocks of WAC as it outcrops at the western margin of the Pan African belt. The Ho gneisses in conclusion are believed to have formed in continental subduction during the Pan African collision. These interpretations therefore, support the previous work that proposed easterly subduction of the rifted margin of WAC (Affaton et al., 1991; Agbossoumondé et al., 2004; Attoh and Nude, 2008) for the Pan – African Dahomeyide orogenic belt.

6.0 Conclusion

The granitoid gneisses from the Pan African belt, southeastern, Ghana have been studied petrographically and geochemically. The studied granitoids are classified mainly as biotite augen gneisses. Geochemically, the granitoids display mainly granodioritic affinity with few showing tonalitic and quartz - monzonite affinities. They represent various facies of granitoids, from I–type, metaluminous to weak peraluminous, magnesian to ferroan, clacic to calc alkalic and high – K series. The LREE-enriched patterns with negative Eu anomalies observed together with high – K characteristics are typical of many subduction related magmas from island arcs or active continental margins. The rocks show LREEs and LILE enrichment consistent with source with strong affinity to VAG and appear to be characterized by mingling of mantle derived magma and crustally derived melts. Thus, involvement of a recycled component into the mantle, which might be associated with lower crustal material, may be possible. The crustal component may have derived from partial melting of rocks of WAC as it outcrops at the western margin of the Pan African belt. Such an enrichment event accounts for the arc - like signatures of these mantle derived rocks and explains the addition of volatiles to the mantle source. This geochemical signature is likely to be related to metasomatism of the sub – continental lithospheric mantle via crustal recycling. The association of WAC with continental crustal rocks into the mantle may be possible source; this further supports our proposals involving continental subduction during the Pan African collision.

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