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Research Article

GEOCHEMISTRY OF BIOTITE AND ITS IMPLICATIONS TO THE ORIGIN OF BAUCHI AND SAMINAKA CHARNOCKITES, NORTH CENTRAL NIGERIA

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ABSTRACT
Biotites from the charnockites of Bauchi and Saminaka in the Basement Complex of north central Nigeria have been examined. The microprobe data of the analyzed biotites are presented. The behavior of major elements in the examined biotites is discussed according to different discrimination models. Based on the geochemical and petrographical characteristics of the biotites analyzed, the biotite of Bauchi charnockite is transitional in nature and may have been associated with magmas having physicochemical properties between calc-alkaline and peraluminous series while those of Saminaka charnockite is peraluminous in nature. This may have resulted from either magma differentiation by mixing or large-scale crustal contamination.

Key Words: *Geochemistry, petrogenesis, Biotite, charnockite, Bauchi, Saminaka, North central Nigeria*

1. INTRODUCTION
Bauchi and Saminaka areas are located in the Basement Complex of north central Nigeria (Figure 1). They form part of the Precambrian to mid Cambrian northern Nigeria crystalline shield. The Basement Complex consists of migmatite, granite gneiss, granulite gneiss and granitoids which include granites sensuo stricto, diorites and charnockites.

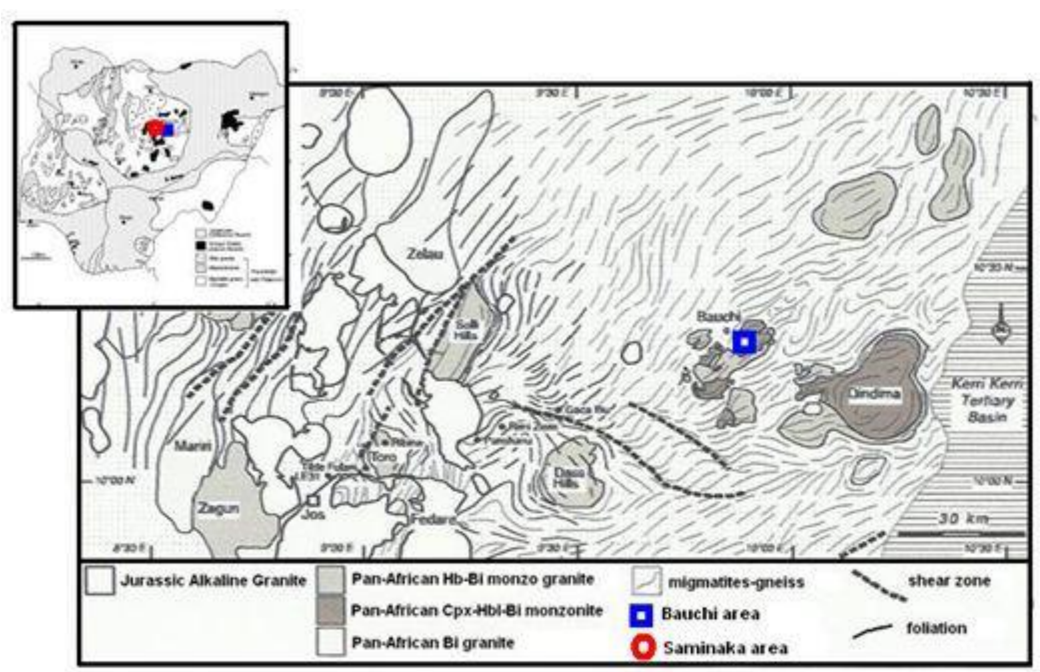

Figure 1: A geologic map showing the location of the study areas (modified Wright, 1971). In set general geological map of Nigeria (modified Olarenwaju, 1998)

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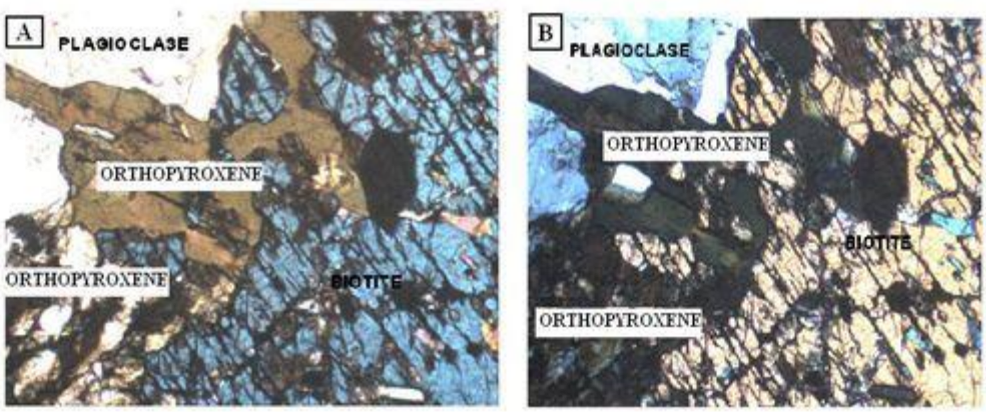
Though, the petrography and isotopic dating have been carried out on these rocks including the granite series as to postulate on their source materials (Wright, 1971; Rahaman, 1988; Dada *et al.*, 1989; Dickin *et al.*, 1991; Olarewaju, 1998) little information on their mineral chemistry is available. Though, Dada (2010) and Dada and Ashano (2012) in their works had highlighted the petrography and geochemistry that characterize diorite and charnockite from Toro, Bauchi, Dass and Saminaka with a view to postulate on the nature of their original magma and suggest petrogenetical relationship to the Younger Granites of the Jos Plateau province.
This paper focuses on chemistry of biotite from charnockites of Bauchi and Saminaka areas, northcentral, Nigeria with aim of determining the nature and conditions of the parental magma vis-à-vis their affliations.

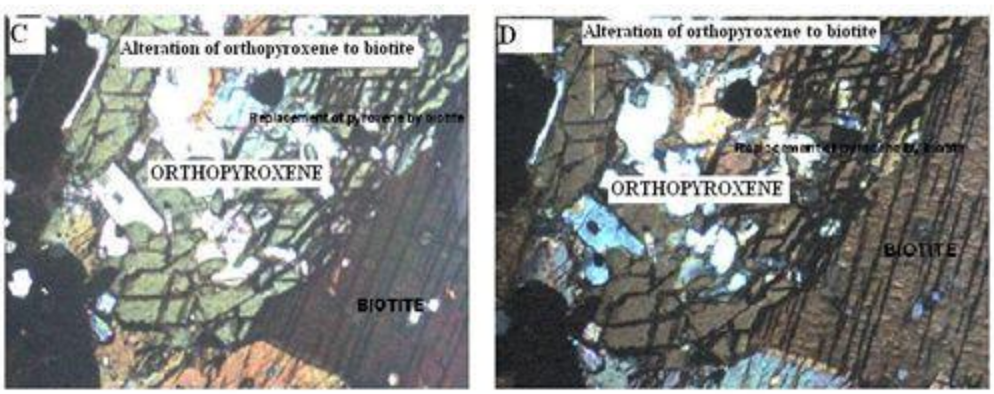
RESULTS

Analytical Methods

Fresh surface samples of charnockites were collected from Bauchi and Saminaka areas, from which twelve representative specimens (polished thin sections) were selected for petrography and electron probe micro analyses for the purpose of this work.



Figures 2 A-B: Photomicrograph of charnockite from Bauchi study area showing biotite replacing orthopyroxene. Figure 2A (ppl) and 2B is xpl (*20)



**Figures 2 C-D: Photomicrograph of charnockite from Saminaka study area showing biotite replacing
orthopyroxene. Figure 2C (ppl) and 2D (xpl) (*20).**

Mineral compositions were determined with a JEOL JXA 8900L electron probe micro analyzer in the Electron micro analyzer Laboratory at the Mc Gill University, Montreal, Canada. Biotite analyses were

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conducted with a 15Kv accelerating voltage, 20nA current, and 10um beam diameter. Natural minerals were used as standards and counting times were 20 seconds on peak and background for all elements.

Petrography and Mineral Chemistry

Photomicrographs of selected slides are shown in Figures 2A, B, C and D. The petrographic studies of the representative samples of Bauchi and Saminaka charnockites show alteration of orthopyroxene to biotite. The representative analytical data are listed in Tables 1 and 2.

Table 1: Representative Biotite Composition (Wt %) of The Bauchi Charnockite

Sample	BA1	BA2	BA3	BA4	BA5	BA6
SiO_2	35.06	34.40	35.44	34.42	34.46	33.54
TiO_2	4.68	4.88	5.10	4.84	5.02	4.86
Al_2O_3	14.12	14.37	13.94	14.28	14.35	14.65
Cr_2O_3	0.098	0.012	0.002	0.012	0.012	0.012
FeO	23.83	26.22	22.86	26.14	26.24	26.56
MnO	0.157	0.125	0.104	0.122	0.122	0.124
MgO	8.30	6.68	8.86	6.48	6.72	7.46
CaO	0.009	0.033	0.013	0.026	0.032	0.028
K_2O	9.55	9.62	9.806	9.68	9.68	9.34
Na_2O	0.072	0.068	0.007	0.075	0.066	0.062
H_2O	0.000	0.000	0.000	0.000	0.000	0.000
Total	95.87	96.41	96.12	96.08	96.70	96.64
Si	5.476	5.350	5.495	5.291	5.408	5.346
Al^{IV}	2.524	2.65	2.505	2.709	2.592	2.654
Total Tet.	**8.000**	**8.000**	**8.000**	**8.000**	**8.000**	**8.000**
Ti	0.550	0.595	0.595	0.515	0.593	0.569
Al^{VI}	0.076	0.053	0.042	0.095	0.062	0.031
Cr	0.012	0.001	0.000	0.001	0.001	0.001
Fe^{2+}	0.6362	1.204	0.6264	0.86	1.0152	0.6556
Fe^{3+}	2.4768	2.64	2.3376	2.976	2.4288	2.7984
Mn	0.021	0.014	0.014	0.004	0.016	0.016
Mg	1.933	1.245	2.048	1.405	1.572	1.729
Total Oct.	**5.705**	**5.752**	**5.663**	**5.856**	**5.688**	**5.800**
Ca	0.002	0.005	0.002	0.004	0.005	0.005
Na	0.022	0.016	0.002	0.005	0.020	0.019
K	1.903	1.874	1.94	1.861	1.938	1.853
A Site	**1.927**	**1.895**	**1.944**	**1.87**	**1.963**	**1.877**
$Fe^{3+}/(Fe^{2+}+Fe^{3+})$	0.7956	0.6868	0.7887	0.7758	0.7052	0.8102
Mg/(Mg+Fe)	0.3831	0.2446	0.4086	0.2681	0.3134	0.3336
Fe/(Fe+Mg)	0.6169	0.7554	0.5914	0.7319	0.6866	0.6664

Table 2. Representative biotite composition (wt %) of the Saminaka charnockite

Sample	SA1	SA2	SA3	SA4	SA5	SA6
SiO_2	34.75	34.64	34.70	34.28	34.45	34.32
TiO_2	4.67	4.47	4.20	3.92	4.23	4.45
Al_2O_3	13.74	13.78	14.28	13.86	13.67	13.72
Cr_2O_3	0.022	0.015	0.000	0.021	0.022	0.021
FeO	26.15	27.76	27.25	28.76	28.42	28.35
MnO	0.141	0.188	0.144	0.165	0.168	0.148
MgO	5.88	6.08	5.93	5.86	5.83	5.85
CaO	0.031	0.000	0.039	0.005	0.036	0.034
K_2O	9.41	9.46	9.35	9.43	9.47	9.45
Na_2O	0.079	0.088	0.042	0.060	0.072	0.073
H_2O	0.000	0.000	0.000	0.000	0.000	0.000
TOTAL	94.87	96.48	95.92	96.37	96.37	96.42
Si	5.464	5.485	5.501	5.465	5.484	5.459
Al^{IV}	2.536	2.515	2.499	2.535	2.516	2.541
Total Tet.	**8.000**	**8.000**	**8.000**	**8.000**	**8.000**	**8.000**
Ti	0.552	0.532	0.501	0.470	0.507	0.533
Al^{VI}	0.01	0.057	0.169	0.069	0.049	0.031
Cr	0.003	0.002	0.000	0.003	0.003	0.003
Fe^{2+}	1.2026	1.132	1.1218	1.075	1.1526	1.1502
Fe^{3+}	2.6304	2.544	2.4912	2.76	2.6304	2.6208
Mn	0.019	0.025	0.019	0.022	0.023	0.02
Mg	1.331	1.435	1.402	1.393	1.383	1.387
Total Oct.	**5.748**	**5.727**	**5.704**	**5.792**	**5.748**	**5.745**
Ca	0.005	0	0.007	0.001	0.006	0.006
Na	0.024	0.027	0.013	0.019	0.022	0.023
K	1.888	1.911	1.891	1.918	1.923	1.918
A Site	**1.917**	**1.938**	**1.911**	**1.938**	**1.951**	**1.947**
$Fe^{3+}/(Fe^{2+}+Fe^{3+})$	0.6863	0.6921	0.6895	0.7197	0.6975	0.7588
Mg/(Mg+Fe)	0.2577	0.2808	0.2796	0.2664	0.2677	0.2689
Fe/(Fe+Mg)	0.7423	0.7192	0.7204	0.7336	0.7323	0.7311

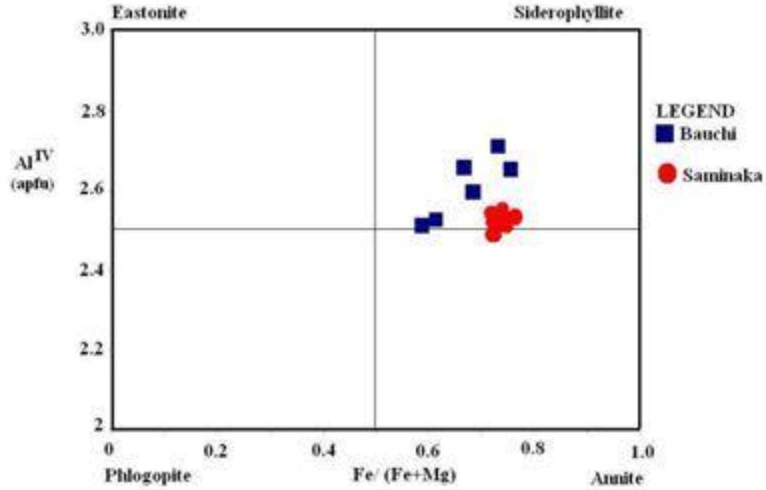

Figure 3: Compositional Classification of Biotite from Charnockites of Bauchi and Saminaka (After Deer et al., 1986)

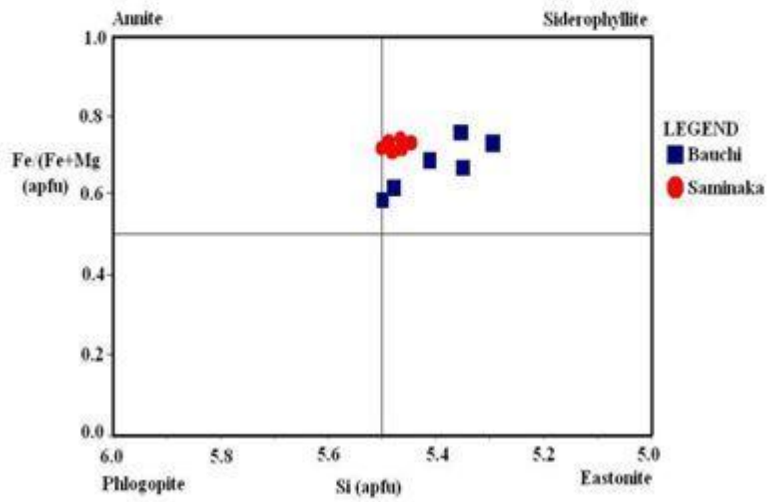

Figure 4: Plot of Si (apfu) vs. Fe/ (Fe+Mg) for Charnockites of Bauchi and Saminaka (After Makutu et al., 2004)

Bauchi Charnockite:

Biotite is the most abundant ferromagnesian mineral in Bauchi charnockite. It varies in sizes, shapes, texture and forms up to 10 modal percent of the rocks. There are two generations of biotites: the primary (euhedral-subhedral) and secondary (subhedral-anhedral) which developed from previously existing hornblende or orthopyroxene (Figures 2AandB). The primary generation type of biotite is euhedral-subhedral, tabular or lamellar and showed strong pleochroism (yellowish-brown to dark brown or reddish brown). Some of the grains of secondary generation type biotite are chloritized and also occurred interstitially with feldspars and quartz, replacing hornblende and/ orthopyroxene. This suggests that the rock may have suffered retrograde metamorphism.

Microprobe analyses (Tables 1) show that biotite compositions from Bauchi charnockite fall within the siderophyllite with high Al contents. Though, two of the samples are tending towards annite at the boundary between annite and siderophyllite (Figures 3 and 4). The biotite in Bauchi charnockite has the following compositions: SiO_2 (33.18-35.55 wt %), FeO (22.86-29.28 wt %), Al_2O_3 (13.94-14.92 wt %),

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K_2O (9.15-9.81 wt %) and TiO_2 (4.29-5.10 wt %) (Table 1). The siderophyllitic biotite is rich in Al (apfu) in the tetrahedral (2.51-2.71) but poor in the octahedral sites (0.01-0.1). The biotite has lower Si contents. It generally has high Al, Fe and low Mg- content (FeO/MgO (2.58-5.50), Mg# (0.24-0.41). The range of molar Fe / (Fe+Mg) is high with an average of approximately 0.67. They show high oxidation state (Fe^{3+} / Fe^{2+} + Fe^{3+} = 0.62 – 0.76, average = 0.67) (Table 1).

Structural formulae calculated on the basis of 22 positive charges show that Si and Al apfu generally fill the tetrahedral sites (Table 1). Though biotite from these rocks contains larger amounts of Al and lower Si in the tetrahedral site. From Table 1, the octahedral sites, however, display slightly more variability between 5.66 to 5.80 cations p.f.u. The A site ranges between 1.87 to 1.96 cations pfu. All these indicate that biotites are close to the ideal stoichiometric values.

Saminaka Charnockite:

There are two generations of biotite in Saminaka just like the ones from Bauchi. The primary is euhedral-subhedral while the secondary is developed from previously existing hornblende or orthopyroxene. It also has abundant ferromagnesian mineral and varies in sizes, shapes and texture. It forms up to 12 percent of modal composition of the rocks. They are euhedral-subhedral, tabular or lamellar and show a strong pleochroism (yellowish-brown to dark brown or reddish brown). Like it occurred in Bauchi, some of the grains of secondary biotite are chloritized and interstitial with feldspars and quartz, replacing hornblende and/ orthopyroxene. This suggests that the rock had suffered retrograde metamorphism.

Microprobe analysis result (Table 2 and Figures 3 and 4) shows that biotite compositions from Saminaka charnockite fall within the siderophyllite with high Al contents. However, Figures 3 and 4 shows that all biotite from Saminaka are tending towards annite, they plot on the borderline between annite and siderophyllite. The biotite in Saminaka charnockite has 34.28-34.75 wt% SiO_2, 27.25-29.15 wt% FeO, 13.72-14.28 wt% Al_2O_3, 9.35-9.47 wt% K_2O and 3.92-4.67 wt% TiO_2 (Table 2). The siderophyllite molecule rich biotite is rich in Al in the tetrahedral site (2.50-2.54) but poor in the octahedral site (0.01-0.17). The biotite also displays lower Si contents.

They generally have high Al, Fe and low Mg- content (FeO/MgO =4.57-5.13; Mg#=0.25-0.28). The range of molar Fe / (Fe+Mg) is high with an average of approximately 0.73. They show high oxidation state (Fe^{3+} / Fe^{2+} + Fe^{3+} = 0.72 – 0.74, average = 0.73) (Table 2). Structural formulae calculated on the basis of 22 positive charges show that Si and Al cations pfu generally fill the tetrahedral sites (Table 2). Though biotites from these rocks contain larger amounts of Al and lower Si in the tetrahedral site. From Table 2, the octahedral sites, however, display slightly variability between 5.75 to 5.79 cations p.f.u. The A site ranges between 1.91 to 1.95 cations p.f.u. These also indicate that biotites are close to the ideal stoichiometric values.

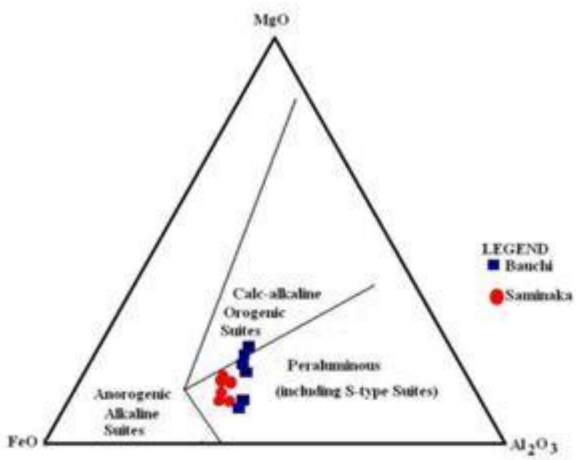

Figure 5: Plot of Bauchi and Saminaka charnockites on Al_2O_3-FeO_t-MgO Ternary Biotite Discrimination Diagram (After Abdel-Rahman, 1994)

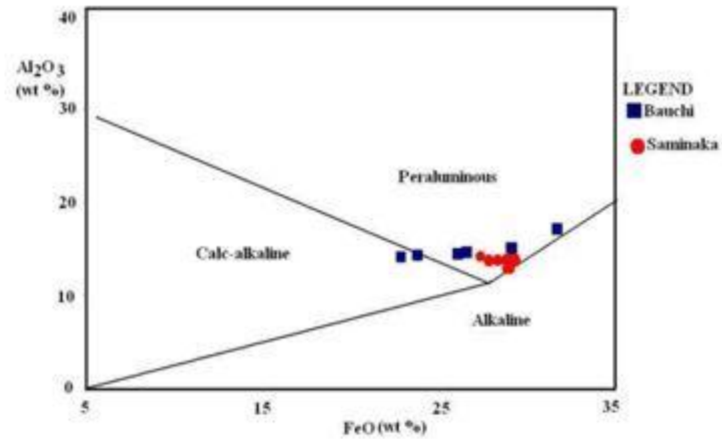

Figure 6a: Bivariate Al_2O_3-FeO_t plot for biotites hosted in charnockites of Bauchi and Saminaka (After Abdel-Rahman, 1994)

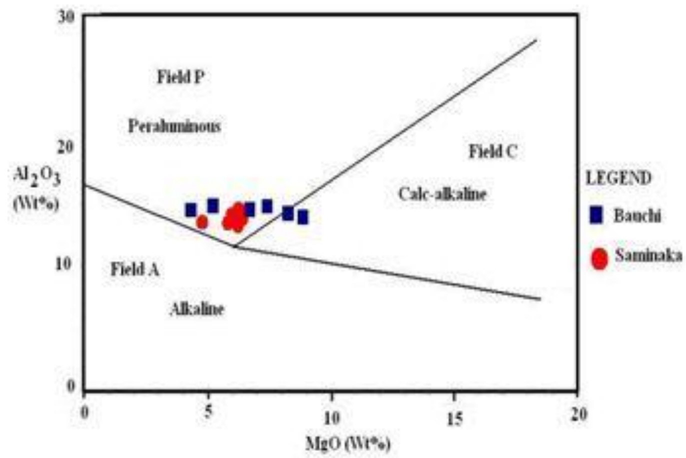

Figure 6b: Bivariate Al_2O_3-MgO Plot for Biotites Hosted in Charnockites of Bauchi and Saminaka (After Abdel-Rahman, 1994)

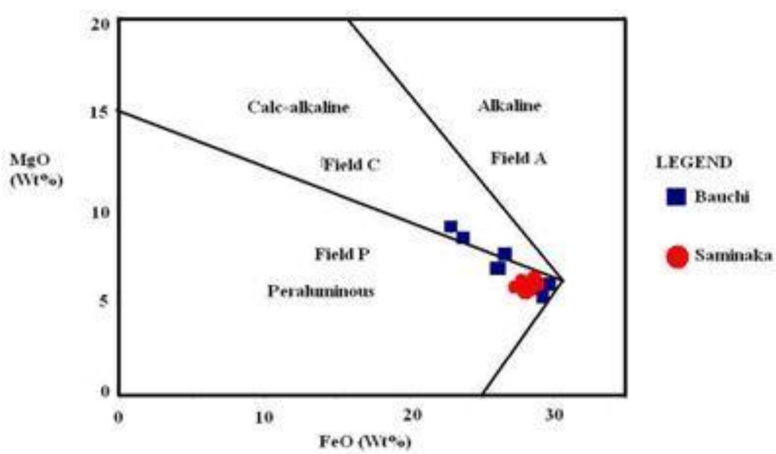

Figure 6c: Bivariate MgO-FeO plot for Biotites Hosted in Charnockites of Bauchi and Saminaka (After Abdel-Rahman, 1994).

DISCUSSION

Biotite is a significant ferromagnesian mineral in most intermediate and felsic igneous rocks (Masoudi and Jamshidi Badr, 2008). It has been used to describe the nature of granitic magma (Abdel-Rahman, 1994; Barrier and Cotton, 1979; De, 1973; Foster, 1960; Masoudi and Jamshidi Badr, 2008; Moazamy, 2006; Nachit *et al.*, 2005; Neiva, 1976; Nockolds, 1947; Sapountzi, 1976; Shabbani and Lalonde, 2003; Speer, 1984).The microprobe analyses data for the studied biotites are plotted on MgO-FeO-MgO, Al_2O_3-FeO, Al_2O_3-MgO and MgO-FeO discrimination diagrams (Figures 5-8). Based on Abdel-Rahman (1994) classification of biotites from granitic magmas, biotites in anorogenic alkaline suites (Field A) are mostly iron-rich, siliceous biotites (near annite) with an average FeO/MgO ratio of 7.04. Those in peraluminous (including S-type) suites (Field P) are siderophyllitic in composition and have an average FeO/MgO ratio of 3.48; whereas biotites in calc-alkaline orogenic suites (Field C) are moderately enriched in Mg; with an average FeO/MgO ratio of 1.76.The investigated biotites are found in fields P and C (Figures 5-8). The average FeO/MgO ratio for Bauchi charnockite is 3.48 while the value for Saminaka charnockite is 4.71. The value for Bauchi charnockite is the exactly value suggested by Abdel- Rahman (1994) for peraluminous field though Figures 5-8 reveal that this biotite straddle in the peraluminous /calc-alkaline fields. The value for Saminaka charnockite is higher than the average value for peraluminous (Field P) but lower than the average value for alkaline suite (Field A). This suggests that based on chemistry of biotite, Bauchi charnockite is transitional between calc-alkaline and peraluminous magma while Saminaka charnockite are from peraluminous magma.When one compares the microprobe data of biotites from Toro diorite from the same region (Dada and Ashano, 2012), they are similar to biotite from Bauchi charnockite than to Saminaka charnockite. The biotites of Toro diorite have higher Al, Fe and low Mg, Si contents (Al_2O_3=13.84-16.23 wt %; FeO = 19.88-24.97 wt %; MgO= 6.64-11.22 wt %; SiO_2 = 35.65-36.44 wt %). On the biotite discrimination diagrams, biotites from Toro diorite also fall within the peraluminous/calc-alkaline suites (Dada and Ashano, 2012).

CONCLUSIONS

Based on the geochemical and petrographical characteristics of the biotites analyzed, the biotite of Bauchi charnockite is transitional in nature and may have been associated with magmas having physicochemical properties between calc-alkaline and peraluminous series while those of Saminaka charnockite is peraluminous in nature. This may have resulted from either magma differentiation by mixing or large-scale crustal contamination (Altherr *et al.*, 2000; Barbarin, 1999; Chappell and White, 1974; John and Wooden, 1990; Petro *et al.*, 1979; White and Chappell, 1983).

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REFERENCES

Abdel-Rahman A (1994). Nature of Biotites from Alkaline, Calc-alkaline, and Peraluminous Magmas. *Journal of petrology* **35**(2) 525-541.

Altherr R, Holl A, Hegner E, Langer C and Kreuzer H (2000). High- potassium, Calc-alkaline I-type plutonism in the European Variscides: northern Vosges (France) and northern Schwartzwald (Germany). *Lithos* **50** 51-73.

Barbarin B (1999). A review of the relationships between granitoid types, their origins and their geodynamic environments. *Lithos* **46** 605-626.

Barriere M and Cotton J (1979). Biotites and associated minerals as markers of magmatic fractionation and deuteric equilibration in granites. *Contr. Miner. Petrol* **70** 183-92.

Chappell BW and White AJR (1974). Two contrasting granite types. *Pacific Geology* **8** 173-174.

Dada OA (2010). Geochemistry of the pyroxenes, amphiboles and biotite from dioritic and charnockitic rocks of Saminaka, Toro, Bauchi, and Dass, North central, Nigeria. Unpublished M.Sc Thesis, University of Jos, Nigeria**.**

Dada OA and Ashano EC (2012). Application of Biotite Composition in Determination of Petrogenesis of Diorites from Toro and Dass, North Central, Nigeria. *International Journal of Science and Technology* **1**(4) 164-169.

Dada SS, Lancelot JR and Briqueu L (1989). Age and origin of the annular charnockitic complex at Toro northern Nigeria: U-Pb and Rb-Sr evidence. *Journal of African Earth Sciences* **9** 227-234.

De Albuquerque GAR (1973). Geochemistry of biotites from granitic rocks, northern Portugal. *Geochim. Cosmochim. Acta* **37** 1779-802.

Deer WA, Howie A and Sussman J (1986). *An interdiction to rock- forming Minerals, 17th edition.* Longman Ltd, UK**,** 528.

Dickin AP, Halliday AN and Bowden P (1991). A Rb-Sr and Nd isotope study of the basement and Mesozoic ring complexes of the Jos Plateau, Nigeria. *Chemical Geology (Isotope Geoscience Section)* **94** 23-32.

Foster MD (1960). Interpretation of the composition of trioctahedralmicas. *US Geolofical Survey Prof.* **354B** 1-49.

John BE and Wooden J (1990). Petrology and geochemistry of the metaluminous to peraluminous Chemehuevi Mountains Plutonic suite, southeastern California In: Anderson, J.L. (edited) The Nature and Origin of Cordilleran Magmatism. *Geological Society of America*, Memoir **174**(25) 71-98.

Lalonde A and Bernard P (1993). Composition and colour of Biotite from granites. *Canadian Mineralogist* **31**(31) 203-217.

Makutu MN, Kanika M, Bwanga N, Nguangu K and Mpoyi K (2004). Petrology and Geochemistry of igneous rocks from Noqui Alkaline Complex. *Bulletin du Centre de Recherces Geologiques et Minieres* **V**(1).

Masoudi F and Jamshidi Badr M (2008). Biotite and Hornblende composition used to investigate the nature and thermobarometry of Pichagchi pluton, northwest Sanandaj-Sirjan metamorphic belt, *Iran. Journal of Science*, Iran **19**(4) 329-338.

Moazamy F (2006). Application of Biotite Composition in determination of Tectonic Setting of Granitoids of Borujerd-Hamedan, M.S.C. Thesis (in Farsi), *Tarbiat Moalem university of Iran* 215.

Nachit H, Ibhi A, Abia EH and Ben Ohoud M (2005). Discrimination between Primary magmatic biotites, reequilibrated biotites and neoformed biotites. *C. R. Geoscience* **337** 1415-1420.

Neiva AMR (1976). The geochemistry of biotites from granites of northern Portugal with special reference to their tin content. *Ibid* **40** 453-466.

Nockolds SR (1947). The relation between chemical composition and paragenesis in the biotite micas of igneous rocks. *American Journal of Science* **22(**39**)** 401-20.

Petro WL, Vogel TA and Wilband JT (1979). Major-element chemistry of plutonic rock suites from compressional and extensional plate boundaries. *Chemical Geology* **26** 217-235.

Olarewaju VO (1998). Mineral Chemistry and geothermometry of plutonic charnockitic rocks of northern and southwestern Nigeria. *Journal of Mining and Geology* **34**(2) 157-170.

Rahaman MA (1988). Recent Advances in the Study of Basement Complex of Nigeria, In: Precambrian

Geology of Nigeria. *Geological Survey of Nigeria Special Publication* 11-44.
Shabbani AT and Lalonde A (2003). Composition of Biotite from Granitic Rocks of the Canadian Appalachian: A potential tectonomagmatic indicator. *The Canadian Mineralogist* **41** 1381-1396.
Speer JA (1984). Micas in igneous rocks, In Micas (S.W. Bailey, edited) *Revised Mineralogy* **13** 299-356 Piedmont, *U.S.A. Canadian Miner* **19** 35-46.
White AJR (1979). Sources of granite magmas. *Geological Society of America, Abstracts with Programs* **11** 539.
White AJR and Chappell BW (1983). Granitoid types and their distribution in the Lachlan Fold Belt, southeastern Australia, In: Roddick, J.A. (Edited) Circum-PacificPlutonic Terranes. *Geological Society of America*, Memoi, **159** 21-34.
Wright EP (1971). Basement Complex, *In the geology of the Jos Plateau (Editors: Macleod, N., Turner, D.C. and Wright, E.P.). Geological Survey of Nigeria Bulletin* **32**(1).