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Petrogenesis of A-type Granitoids of Bauchi Migmatites NE, Nigeria. From Geochemical Perspective

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Abstract *- A-type granitoids constitute a proportion of granitoid in the Bauchi granitoids, and they consist of syenogranites, monzogranites, granodiorites, and charnockites. The felsic and mafic members were formed through partial melting of the lower crust plus mingling and mixing of melts from the mantle. The granitoids are dominantly peraluminous to slightly metaluminous, which have high Fe content that maybe Fe-rich biotite and Fe-hornblende and also high total alkalis, Y, Nb, and REE with low CaO, MgO, and Sr abundances and high FeO/(FeO+MgO) ratios are the major features of these granitoids which make them be classified as collisional A2-type granite. Chondrite-normalized REE patterns show a negative Eu anomaly showing local fractionation during partial melting of lower crustal rocks.*

Keywords *- A-type granites, Bauchi, granulite facie, partial melting, migmatites*

I. INTRODUCTION

A-type granitoids were defined by Loiselle and Wones (1979) are androgenic granitoids that have high alkalis (Na_20+K_20), FeO/(FeO+MgO) ratios, Ga/Al, Zr, Y, Nb, F, Cl, and REE (except Eu), as well as low CaO and MgO (Collins et al., 1982; Whalen et al., 1987). They also have minerals like biotite, ferro hastingsite, amphibole, and pyroxene that make them ferromagnesian (Collins et al., 1982; Whalen et al., 1987; Eby, 1990). The high F contents in A-type granites could be due to fractional crystallization processes, while the high-halogens contents are not a distinguishing feature of A-type granite (Landenberger and Collins 1996)

A-type granitoids may be emplaced during a tectonic-magmatic episode, or other orogenic processes like partial melting, as such calling it androgenic should not be used to characterize A-type granitoids (e.g., King et al.,1997; Barbarin, 1999; Wu et al., 2002; Kebede and Koeberl, 2003; Mushkin et al., 2003). (Eby 1990,1992) further subdivides A-type granites into A_1 and A_2. A_1 are those that are formed at continental rifts or due to intraplate magmatism, while A_2-type are those formed by partial melting of continental crust or underplating of the mafic crust through continental-continental collision or the subduction of oceanic crust. A_1 granitoids have less Y/Nb ratio <1.2 while A_2 have higher Y/Nb> 1.2. A_1 granitoids are formed within oxidized environments, while A_2 is formed within reduced environments.

There are so many models that have been proposed for the origin of A-type granitoids:

(1) Partial melting of depleted hydrous felsic lower crust rocks, of granulitic meta igneous sources (Collins et al., 1982; Clemens et al., 1986; Whalen et ah, 1987).

(2) The Partial melting of charnockitic lower crust due to collision of continents, formed as a residue from an earlier I-type magma extracted, at temperatures of about >900°C, in a collision tectonic setting can form A-type granitoid (Landenberg-and Collins, 1996).

(3) calc-alkaline granitoids can also form A-type granitoids through dehydration (Anderson, 1983; Creaser et al., 1991).

(4) Tonalite that rich in amphibole at about 6-10 kbar, forms a granulitic residue that can generate melts similar to A-type granites (Skjerlie and Johnston, 1992).

(5) Basaltic magmas or rocks can form A-type granitoid through differentiation (Loiselle and Wones, 1979; Eby, 1992; Turner et al., 1992; Beyth et al., 1994).

(6) Felsic igneous rock-bearing water can form A-type granite through partial melting (King et al., 1997).

II. REGIONAL GEOLOGY

Nigeria is located in between the zone of oblique collision of the West African craton, southeast of the Congo craton, and Toureq shield to the north Fig.1. Basement rocks of Eastern Nigeria consist of Pre-Cambrian; Migmatite-gneiss, shiest belt, and the Pan-

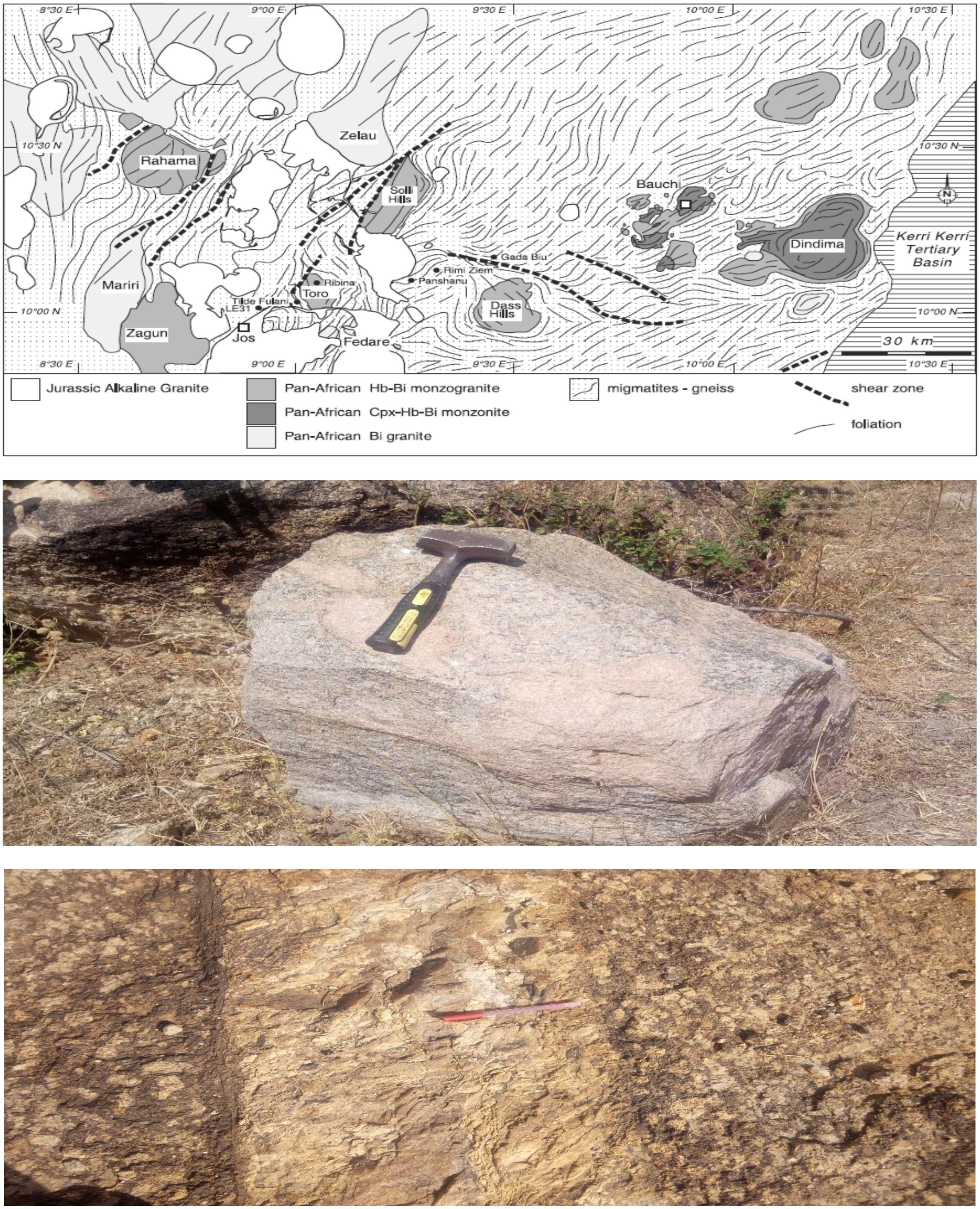

Fig 1: (a) Geology map of the study area
(b) Field picture of A_2-type granitoid
(c) Field picture of charnockite

African granitoids (Ajibade and Wright, 1989; Caby, 1989; Ferre et al., 1996; Jibrin et al., 2019).

Charnockites are felsic igneous or metamorphic rocks that are characterized by the presence of orthopyroxene or olivine, or garnet. They are formed from dry felsic magmas in the lower crust that form magmatic charnockites or as a result of dehydration of granitic rocks under granulite facie metamorphism. Most metamorphic charnockites are formed under low oxygen fugacity and high CO_2 or salt-rich fluids (Jibrin et al., 2019). Granitoids from Bauchi (figs. 1a,b, and c) were studied in order to ascertain their chemistry and origin

III. Geochemistry

Major, minor, and some trace elements were analyzed by X-Ray Fluorescence Spectrometry at the Nigerian Geoscience Research Laboratory (NGRL). They are presented in table 1.

Most of the samples have silica content greater than 70, indicating their highly felcic. The granites show a trend parallel to the AF side of the AFM diagram, indicating crystallization may be under low oxygen fugacity.

The rocks were classified as nebulites which are the end product of granulite facie metamorphism, and proper granites were formed with varying compositions, ranging from granodiorite to quartz monzonite. They are spread in areas around Yelwa, Bauchi metropolis, Dindima, Alkaleri quarry, Zongoro, Soro, and Tirwun. Nebulites containing orthopyroxene or olivine were described as charnockites (Bauchite), while the others are granites, granodiorite, and quartz-monzonite. The nebulites have compositions ranging from quartz, orthoclase feldspar, plagioclase feldspar biotite, hornblende, orthopyroxene, ferromagnesian minerals, and other accessories.

Chemically, the nebulites show the dominance of negative trends on the hacker variation diagram (Fig 3); this shows the effect of metamorphic fractionation during the formation of the rocks. They are also dominantly peraluminous with a few slightly metaluminous, also showing sources from dominantly S-type granitoids(Fig 2ai). They are also ferroan (A_2-type) and slightly magnesian (calc-alkaline); on frost MALI index, they are calcic to calc-alkaline, also indicating the dominance of the felsic nature of the rocks with an increase in metamorphism (Fig 2aii & 2aiii). Tectonically, they are syn-collisional to post-collisional granitoids, and this also confirms that they were sourced from the S and I-type by partial melting of the lower crust with minor input from the mantle under granulite metamorphism during the Pan-African orogenic event, suggesting that the chemistry of the rocks suggest variation in the major and trace elements which have been modified by interactions with the granitic magmas formed during partial melting processes. The granitoids are A-type granite in the Zr-Nb-Ce-+Y versus FeO/MgO and (K_2O+ Na2O)/ CaO diagrams (Fig 5).

The Bauchi granitoids are characterized as A-type granites (Whalen et al., 1987) or either as alkaline post-collision type falling within the A_2 field (Fig. 5) in the Nb-Y-Zr/4 diagram (Eby, 1992), which reflect their derivation from crustal sources. The granitoids have negative Eu anomalies on the REE chondrite-normalized patterns (Sun, 1982) characterized and $(Ce)_N/(Yb)_N$ ratios ranging from 5 to 20 (Fig. 8).

The granites, granodiorites, and charnockites have deep curves on the chondrite-normalized spider diagram shown in figures 4a and b, and deep curves are at Ti, P, Sr, and Ba, smaller curves at Nb, and LILE / HFSE ratios less than or equals 10 these may be due to the fractionation of sphene (Ti), apatite (Sr e P) and plagioclase (Sr) during formation.

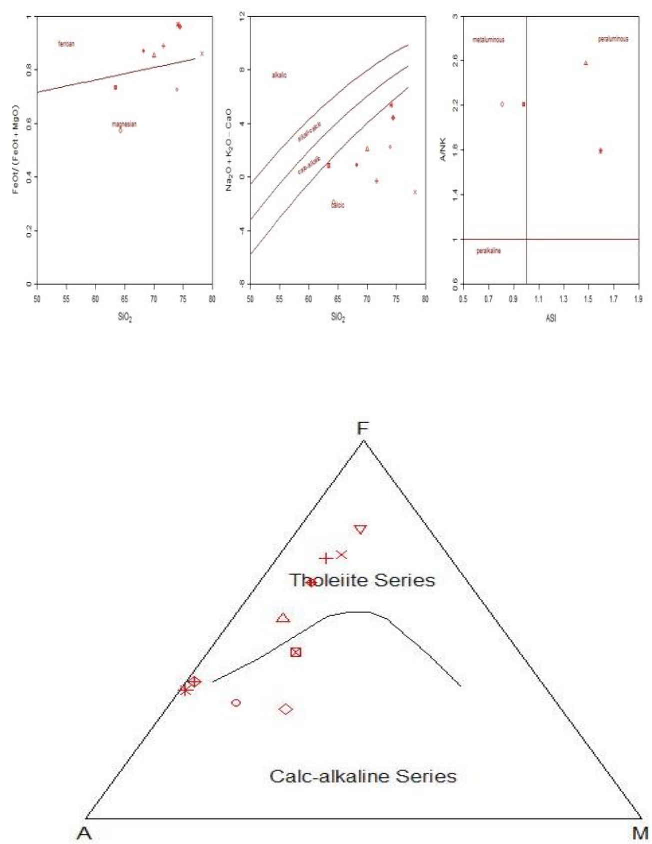

Fig 2. (a) Tecnonic discrimination diagrams modified from (frost et. al 2001) (i) Fe-index against SiO_2 (ii) MALI(modified alkali-lime index) against SiO_2. (iii) ASI (aluminium saturation index; Al/(Ca-1.67+Na+K) against A/NK (Alkalinity index; Al- (K+Na) (b) AFM classification diagram of the granitoids (after Irvine and Barager, 1971)

Table 1. Geochemical composition of Bauchi Granitoids

SiO_2	74	70	71.58	78.2	64.25	80.54	63.41	74.1	74.4	68.2
Al_2O_3	14	13.07	13.4	13.1	15.6	5.7	14.2	13.4	14.27	15
CaO	1.45	2.08	2.07	1.87	6.77	1.01	4.45	0.51	0.45	2.1
MgO	0.74	1	0.7	0.45	2.14	0.87	2.1	0.1	0.12	1.01
SO_3	0.05	0.054	0.044	0.014	0.065	0.06	0.12	0.02	0.014	0.021
K_2O	3.19	3.17	1.24	0.34	1.8	0.45	4.1	3.87	4	1
Na_2O	0.45	1	0.54	0.42	3.11	0.5	1.21	2	0.87	2
TiO_2	1.1	1.21	1.7	0.65	1.4	1.02	1.6	1.2	1.45	1.74
MnO	0.13	0.1	0.087	0.17	0.12	0.2	0.11	0.057	0.062	0.14
Fe_2O_3	2.15	6.45	6.1	3.1	3.21	6.7	6.47	3.41	3.14	7.4
F+M	2.89	7.45	6.8	3.55	5.35	7.57	8.57	3.51	3.26	8.41
$Fe_2O_3/(Fe_2O_3+MgO)$	0.743945	0.865772	0.897059	0.873239	0.6	0.885073	0.754959	0.97151	0.96319	0.879905
K/N	7.088889	3.17	2.296296	0.809524	0.578778	0.9	3.38843	1.935	4.597701	0.5
$Al_2O_3/(K_2O/Na_2O)$	1.974922	4.123028	5.835484	16.18235	26.95333	6.333333	4.190732	6.925065	3.103725	30
V	220	10.451	7.12	0.01	70	284.01	300	320.14	430.12	80.41
Cr	520.01	8.744	1.1	0.01	10.04	244.22	124	287.2	247	45
Cu	260.014	258.01	280.77	270.1	310.2	350.44	362.45	321	310.44	310.2
Sr	937	1000	345	430.11	1390	120.55	2447	741.24	830.24	1510
Zr	670.54	3850	3160.15	2280	5140	641.2	2710.01	245.5	2440.1	1900
Zn	70.1	210.54	260.44	240.4	260.7	342.42	270	347.17	420.44	280.45
Ce	0.03	0.01	0.15	0.053	0.05	0.05	0.04	0.33	0.34	0.45
Pb	370	100.74	930	310	120	32.44	8.741	11.4	12.01	12
Ba	700	7800	6800	10.74	5950.1	214.2	878.12	478.87	1000	1700
Ga	1.11	20.12	10.4	4.41	38.78	12.45	16.12	14.51	12.45	0.01
As	0.01	0.01	0.01	0.01	0.01	0.54	0.01	0.041	0.01	0.01
Sc	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Y	0.01	0.45	0.32	0.04	0.01	0.042	0.01	0.021	0.01	0.24
Ni	0.02	0.01	0.014	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Rb	470	131.11	130.12	115.45	280	30.12	41.01	21.77	0.01	350
Nb	0.01	0.01	0.01	0.04	0.01	0.01	0.01	0.21	0.01	0.01
Ru	0.48	0.01	0.86	0.01	0.01	0.24	0.01	0.01	0.01	0.38
Ta	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.122	0.01	0.01
W	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.021	0.01	0.01
Hf	42.01	54.1	54.01	54.45	24.47	44.22	41.77	34.22	42.1	52.12
Sb	0.01	1.7	0.14	0.54	2.147	0.01	0.01	0.14	0.01	0.01
Orthoclase	16.34575	15.60451	4.62102	0.378425	18.49519	0	19.4775	21.87277	22.44375	2.39807
Albite	3.8115	8.47	4.5738	3.5574	26.3417	4.235	10.2487	16.94	7.3689	16.94
Anorthite	7.192	10.3168	10.2672	9.2752	12.94752	4.678487	20.36668	2.5296	2.232	10.416
Quartz	56.0603	47.5877	59.2582	70.4516	18.03992	73.63757	30.55988	46.5465	53.0536	48.236
Hematite	2.15	6.45	6.1	3.1	3.21	6.7	6.47	3.41	3.14	7.4
Ilmenite	1.045	1.1495	1.615	0.6175	1.33	0.969	1.52	1.14	1.3775	1.653
Biotite	3.59645	4.495885	3.75764	2.389925	-10.9821	7.365402	6.961546	1.28229	1.530265	4.97949
Amphibole	0	0	0	0	29.16529	0.581802	2.411939	0	0	0
Corundum	7.1733	4.2108	7.4024	8.6364	0	2.610279	0	4.9922	7.6955	6.798
Di	0	0	0	0	4.585846	0	0	0	0	0
Hy	1.843188	2.490795	1.743557	1.120858	3.204391	2.166992	5.23067	0.24908	0.298895	2.515703
Ol	2.14997	6.449911	6.099916	3.099957	3.209956	6.699908	6.469911	3.409953	3.139957	7.399898
Mt	0	0	0	0	3.105154	0	0.614718	0	0	0
Il	0.954046	1.097884	1.602736	0.4588	0	0.795168	1.226272	1.136312	1.380788	1.583057

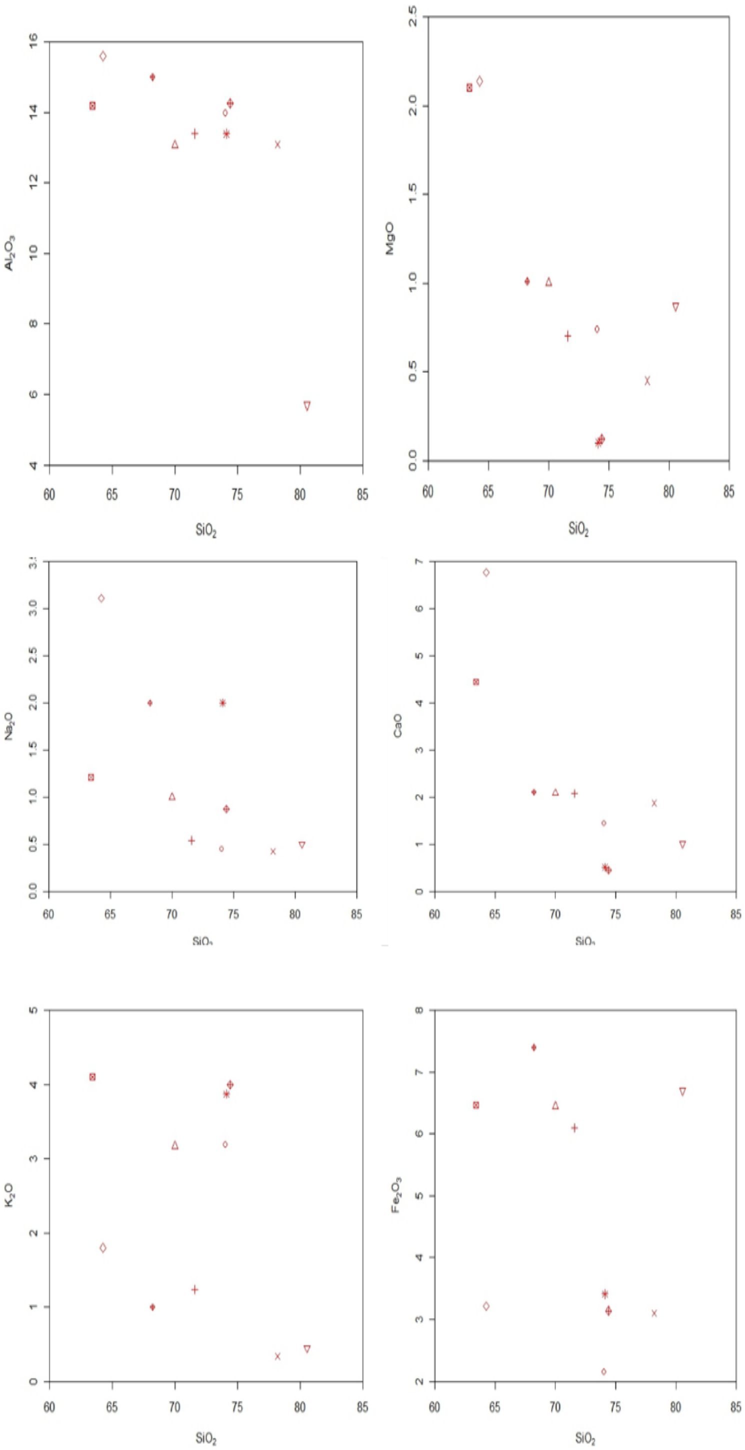

Fig 3. Variation diagram for the major elements of Bauchi granitoids

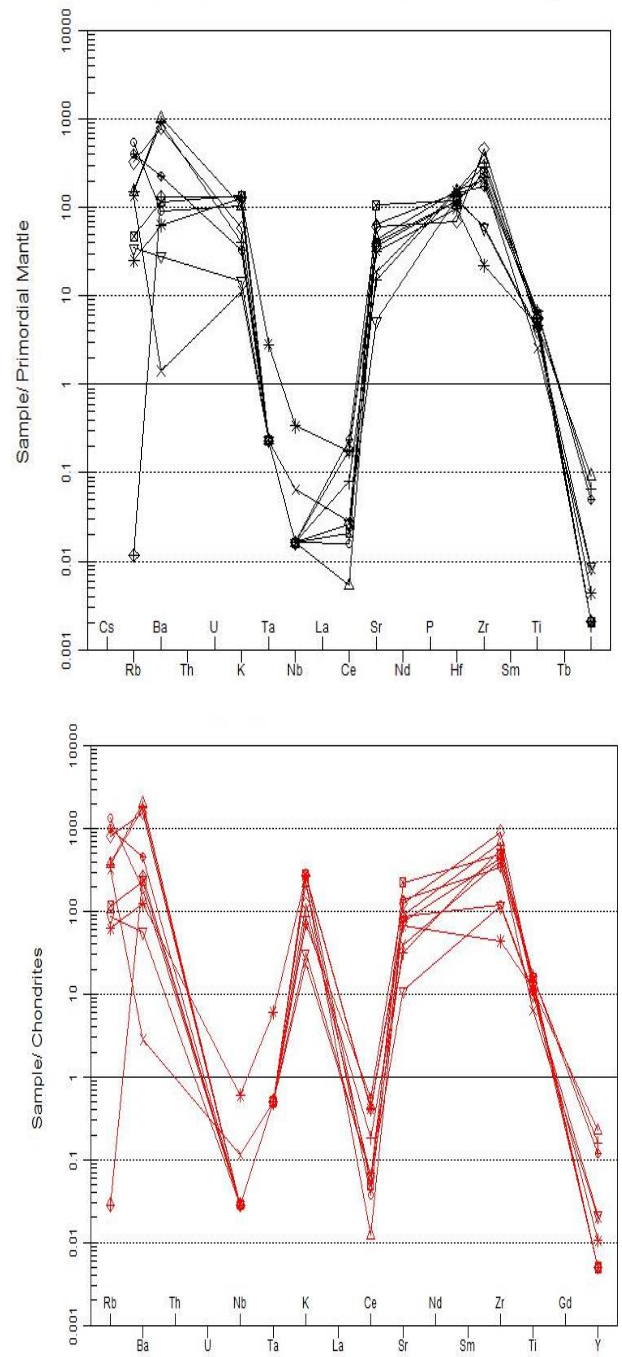

Fig 4. (a) Primitive mantle (Wood, 1979) normalized, race element abundance diagrams (spidergrams) for representative samples of the studied granitoids (b) Chondrite-normalized REE patterns (Sun, 1982) of the studied granitoids

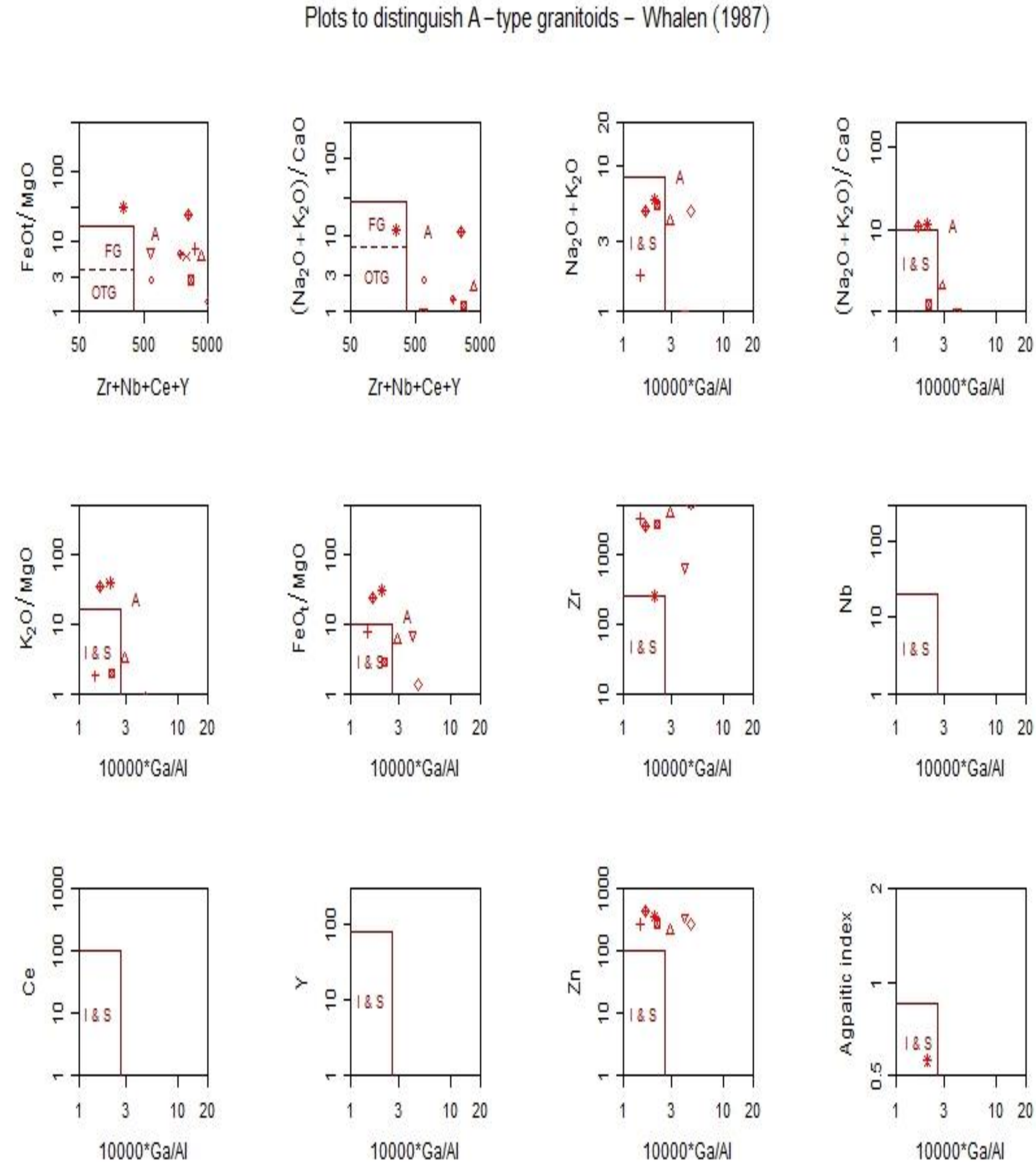

Fig 5. Trace elements Tectonic discrimination diagrams for the studied granitoids (Whalen et al. 1987)

IV. Petrogenesis

The fractionation model could not be applied to the formation of the felsic and mafic-studied rocks because of the different geochemistry signatures they possess, and the intermediate members of the suite represent mixing products between the felsic and mafic members during partial melting of the lower crust. This is very clear even by field and textural relationships. However, some chemical variations of (CaO, K_20, P_20_5, $Ti0_2$, Na_20, Ba, Sr) indicate that magma mixing was not the sole process that occurs (Fig. 3). CaO, K_20, $Ti0_2$ show negative trends in plots versus $Si0_2$ diagrams suggest local fractionation of apatite, alkali feldspar took place during partial melting. The fractionation process that is dominated by feldspar separation is typically significant in most A-type granite systems due to high temperatures and a high proportion of melt that characterize such melts during their emplacement (Clemens et al., 1986; Collins et ah, 1982; Eby, 1992; Dall'Agnol et ah, 1999).

Geochemistry shows the interaction between mantle-derived magmas and lower crust magma generated by partial melting during the collision of west African craton and Congo craton at granulite facie metamorphism. The deep curves at Sr and Ti recorded in the granites spidergrams (Fig. 4a) and REE patterns showing negative Eu anomalies (Fig. 4b) could be related to plagioclase and Fe-Ti oxides residual or either the extraction of plagioclase during generation of calc-alkaline magmas as partial melting increases with depth.

V. Discussion

The Nd values of the granitoids from Bauchi granitoids suggest a crustal component involved in the generation of these granitoids. The geochemistry of these granites suggests crystallization under low $f0_2$ and low or no H_20.

The studied rocks were formed from partial melting of granulite residual rocks that form A-type granitoids that have high K-contents and iron oxide and fluorite. (Collins et al., 1982; Clemens et al., 1986; Whalen et al., 1987). This is similar to the experimental results of Dooley and Patino Douce (1996) and Patino Douce and Beard (1996), which show that high F contents in the source melt favor Al enrichment in the localized melt, even if the parent rock is not oversaturated with alumina it will be like that. Increase F-contents in the melt may be due to the localized fractionation process. This leads fluorite to be a later crystallizing phase. Felsic granulite residues will be deplated in K_2O because of the extraction of the high-K calc-alkaline granitoids, as such could not have generated melts high K_20 contents as recorded in the granitoids. Partial melting of granodiorite and tonalite under vapor-absent conditions will generate A-type granite magmas similar to the studied rocks, the temperature that is required for extraction of magmas generated under absent vapor conditions is at least higher than 900°C. Field evidence, as well as chemical signatures of magma mixing processes in the granitoids, suggests that hot mafic magmas from the mantle were not restricted to heat transfer, but they also entailed chemical interaction with the crustal derived melts.

VI. Summary and Conclusions

The granitoids show chemical and mineralogical characteristics of collisional granitoids or within-plate granite formed under high temperature and pressure. Major and trace element shows that the studied granitoids were formed by partial melting of tonalite or granodiorite lower crust. Field and chemistry show magma mixing processes involving magma from partial melting of felsic granodiorite or tonalite and/or either melt originated from the lithospheric mantle and melted generated from asthenospheric mantle even though in a small amount. The Negative Nd values (-14 to -10), high incompatible elements such as LILE, HFSE, and REE -in the granitoids, shows lithospheric mantle in the area, all showing partial melting at high temperature under granulite facie metamorphic conditions forms these granitoids.

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