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Geochemistry of I-type Granites from the Area Around Gwagwada, Kaduna Nigeria

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Abstract: Major and trace element variation and discrimination diagrams from Gwagwada, Central Nigeria show that the I-type granites of probably deep crustal source of post collision transcurrent geological setting was influenced by older basement materials during emplacement based on the average A/CNK (1.54), Na_2O (3.8), lack of normative corundum as well as their high calc-alkaline and strongly peraluminous nature. The structural high which is evidenced by the high dips and the strain distributions that followed the uplift and late stage magmatism may have released ferro-potassic fluids responsible for either leaching of barium and beryllium as shown by the high barium content in the rocks into or away from the basement and pegmatites. This has serious implications for exploration efforts in the basement.

INTRODUCTION

The petrochemistry of granitic rocks from western and eastern Nigeria has shown that they could be from different tectonic settings (Fitch *et al*., 1985; Ferre *et al*., 1998, 2002). This variation could be as a result of both sources and transport/emplacement mechanism (Petford *et al*., 2000). The petrographic characteristics of granites often reflect strongly on its major element composition, the description of which until recently has been the exclusive preserve of petrologists and geochemists. Now other approaches including magnetic susceptibility studies are used to characterize its emplacement mechanism which reflects its interaction with the surrounding host medium. Ferre *et al*. (2002)'s revelation on the eastern Nigerian terrains has shown the need to look closely at granite compositions in the basement. This has necessitated the interest on this research.

Major element variation in rocks is useful tool in understanding the petro-chemistry of igneous rocks as well as the behavioral patterns of the magma during emplacement and assent from source. Three basic geochemical questions arise when dealing with the geochemistry of igneous rocks (Walter, 2009). These include the composition of the source rocks for the magma is it a primary magma, or did the magma change composition from its source to emplacement location, and lastly what is the cause of the trend in composition, indicating whether these trends are due to magmatic mixing, differentiation, crustal fractionation or anatexis.

Changes in the concentration of the trace elements can be used to place constraints on igneous processes. This is because the incompatible trace elements in minerals like the High Field Strength (HSF) elements e.g., Zr^{4+} and the Large Ion Lithofile (LIL) elements (Sr^{+} and Ba^{2+}), increase in the melt as the magma crystallizes.

I and S type granites was first recognized in south-eastern Australia by Chappell and White (1974) which means granites of igneous and sedimentary origin, respectively. This concept has assumed tremendous impact on petrological and exploratory dimension in granite studies (Blevin and Chappell, 1995). This categorization has often proved useful in targeting certain ores and such an understanding can be of immense benefit to our Nigerian basement metallogeny. In Nigeria, granite suites range in composition from granites, granodiorite, diarites, syenites and tonalitic affinities (Dada, 1995, 1996; Fitches *et al*., 1985; Oyawoye, 1972; Olade, 1976; Rahman, 1988; Rahaman *et al*., 1983, 1988).

MATERIALS AND METHODS

Approximately 5 g of fresh rock samples were used for litho-geochemical analyses in ACTLABS laboratory Canada. Samples were mixed with a flux of lithium metaborate and lithium tetraborate and fused in an induction furnace and run for major oxides and selected trace elements on a combination simultaneous/sequential Thermo Jarrell-Ash ENVIRO II ICP or a Spectro Cirros ICP. Calibration is performed using 7 prepared USGS and CANMET certified reference materials. The analyses utilized the Lithium metaborate/tetraborate fusion ICP Whole Rock Package Code 4B. The fusion process ensures total metals particularly for elements like REE in resistate phases. The Excel file format results which were reported in wt% for major oxides and ppm for the trace elements were used to produce the normative, molar proportions and elemental compositions in Minpet 2.02 Power Norm extension. Where necessary, the calculations were done in excel and copied into the plotting program. The individual plot procedure was selected to suit the individual rock suites available in the software. The variation and ternary plots as well as the discrimination and cationic plots were plotted in Minpet 2.02.

RESULTS AND DISCUSSION

The general geology of the area is made up of migmatites, gneisses and a mix of -8 with pervasive intrusion of granites that range in composition from tonalitic to daciticvariaties (Fig. 1). The tectonically active terrain is evidenced by shear zones and wide spread faulting and fracture patterns. The late stage shearing straddle the compositional variation in these granites.

Petrography: The granites of this area ranged between the medium to coarse grained varieties that formed the Chikun hill chain as elongate north easterly outcrops, to the porphyritic variety around Gwagwada where the feldspars and quartz constitute the phenocrysts set in a ground mass that is composed of biotite, minor muscovite, hornblende and pyroxenes. Microcline is available in minor amounts both in the groundmass and phenocrysts. Vermicular intergrowth between quartz and plagioclase and poikilitic texture involving augite and plagioclase were common in the granites. Compositional zoning within the feldspar phenocrysts occurred in a variety of shapes that ranged from trapezoidal, rhombohedral and square to rectangular laths were common, especially, around Gwagwada (Fig. 2). Close sampling revealed that the zenoliths concordantly aligned with the mineral lineation.

Geochemistry

Classification plot: The classification plots shown in the Fig. 3 were used to classify the granites. Based on the cationic classification or the B-A diagram after Debon and Le Fort (1983) (Fig. 4), the alumina balance of the granitoids of the area which plot as metaluminous leuco granitoids means that the granitoids have high proportion of clinopyroxene +/-primary epidote+/-sphene (Fig. 5 and 6).

Harker plots: The granitoids showed insignificant variation in the major element contents both in the porphyritic and medium-grained varieties. With respect to silica variation, they behaved uniformly and ranged between 66.41-76.59%. The only significant deviation in the silica occurred in the pinkish coarse-grained variety where the silica content was the highest (76.59%) while comparatively the Al_2O_3, Ca_2O and Na_2O were lower. However, the K_2O averagely remained the same with the grey varieties. Al_2O_3 content ranged between 12.52% (in the potassic granite) to 15.59% (in the grey porphyritic varieties). Ca_2O content is very low in the pinkish type to a much higher average in the porphyritic and fine-grained type for 2.21% with the highest maximum of 3.02%. Na_2O and K_2O contents are averagely the same for the granitoids with averages of 3.81 and 3.60%, respectively. The Na_2O content exceeds 3.2% which shows that they are I-type granites[6-16] even though the normative diopside is above 1% and normative corundum is completely absent except for the pinkish GK019 that occurs around Chikun. Total iron content, MnO and MgO show some degree of variation ranging widely for the granitoids. The alkalinity index of the granitoids range between 1.98 and 4.00.

On the Harker diagrams, the major oxides show variation with silica. The negativity or positivity of the slopes fairly defined the trends and their relationships. Generally, the granitoids appear to be of a co genetic source and possibly of the same magmatic suites (Fig. 7-9).

Geotectonic environment: When the alkalinity index values were plotted against silica after Wright (1969), they plotted as calc-alkaline (average 2.68) with a few transiting into the alkaline suite as compared with granitoids of Minna and other northwestern region of Nigeria (Fig. 10).

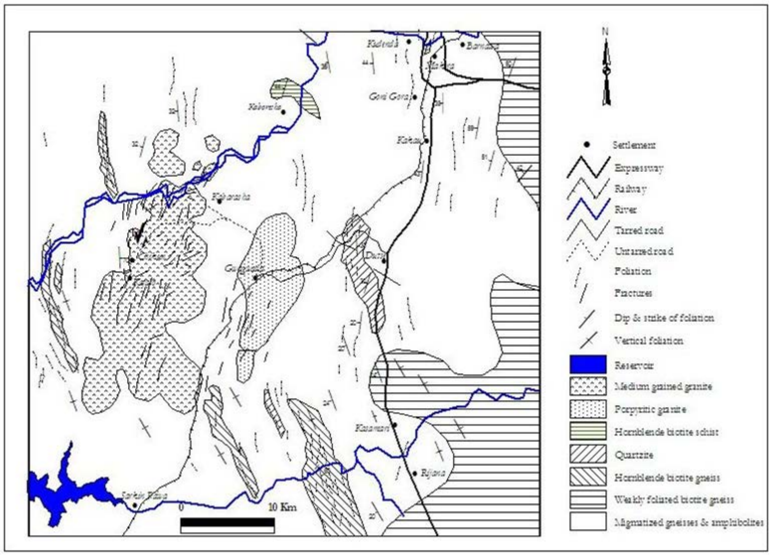

Fig. 1: Geologic map of the study area

Fig. 2: Photograph of porphyritic granites showing weak lineation of zoned feldspar crystals in the North South direction (Gwagwada)

The granitoids plotted in the K_2O vs SiO_2 diagram with fields after Rickwood, majorly as high-k calc-alkaline while a few plotted as medium-k calk-alkaline rocks (Fig. 10).

This compares very well with the post collisional quartz monzodiorites of eastern Nigerian terrains (Ferre *et al*., 1998) except for the slightly higher silica content. In addition, the granitoids plotted in the strongly peraluminous field when A/CNK is plotted against SiO_2. This contrasts sharply with the Madagali granitoids of northeastern Nigeria which plotas mildly peraluminous granitoids (Baba *et al*., 2006) (Fig. 11).

With little variation in paragenesis, the granitoids generally plot as post orogenicgranitoids in the discrimination diagrams by Moniar and Piccoli (1984), calcic, Moniar and Piccoli (1984), rhyodacite to dacites on the Winchester and Floyd discrimination diagrams and Condie and Hunter (1976).

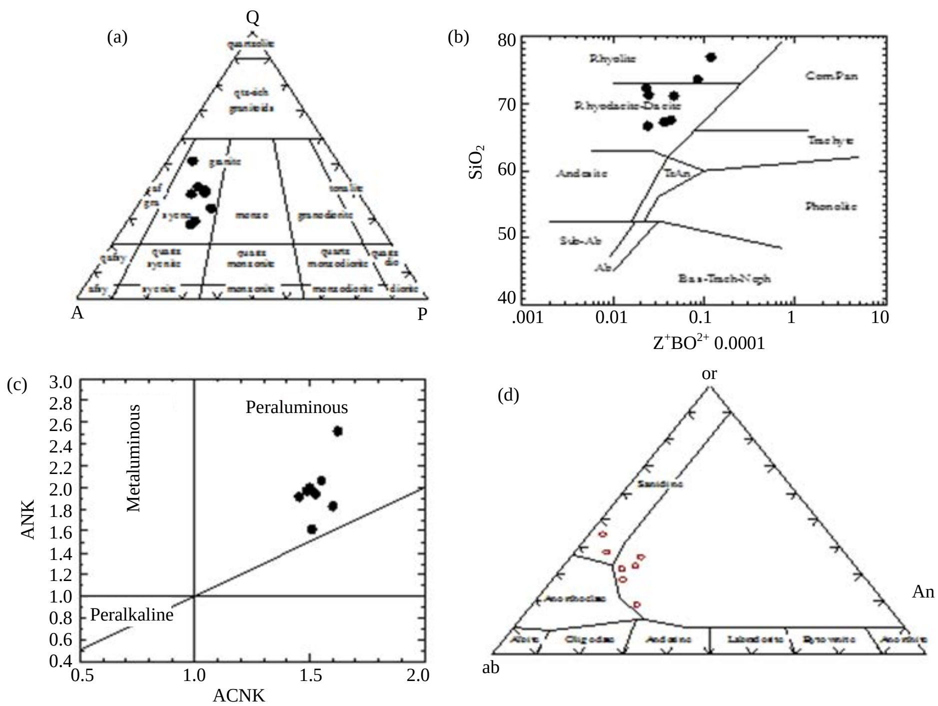

Fig. 3(a-d): The various classification plots for the granites based on the major oxides

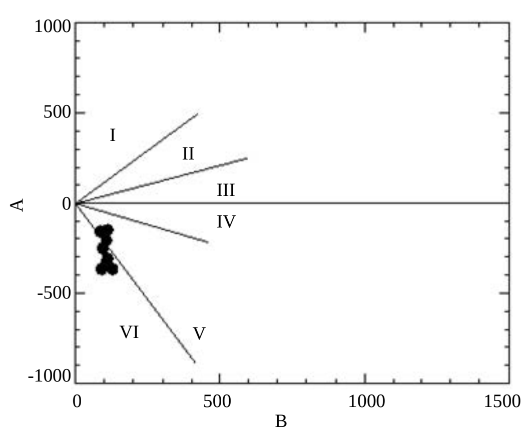

Fig. 4: B-A diagram for the granitoids after Debon and Le Fort (1983) (A=Al-(K+Na+2Ca), B = Fe+ Mg+Ti. I, II and III are peraluminous; IV, V and VI are metalumnous. Squares are medium grained granites, circles are porphyritic granites while the shaded triangle is potassic coarse grained granite

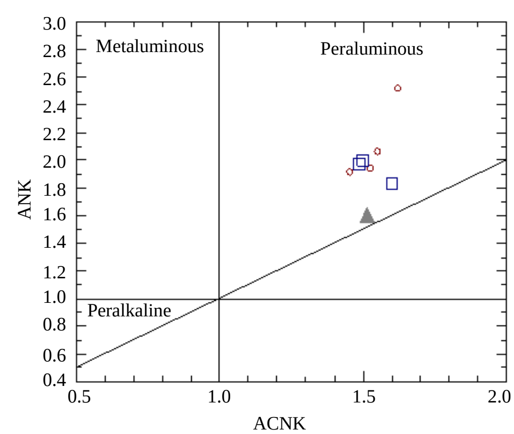

Fig. 5: ACNK-ANK discrimination diagram for the granitoids plotting in the perluminous field

The normative quartz in the granites gives a composition that range between 17.82-35.58%, orthoclase between 10.94-25.81%, anorthite between 5.81-16.19%. The rocks show a normative albite content of 28.09-38.04%. The normative composition indicates the presence of diopside and hypersthene and they are not conrundum normative except for one sample. Olivine is completely absent while accessory apatite is present in percentage that range between 0.2-0.39%. The iron content averages below 1.0%. Generally, based on the normative composition, the granitoids can be classified as silica oversaturated which is reflected by the presence of quartz and hypersthenes in the norm. Tourmaline is clearly mappable in the pegmatite dykes associated with the granites. Olivine is markedly absent even in the modal composition of the rock.

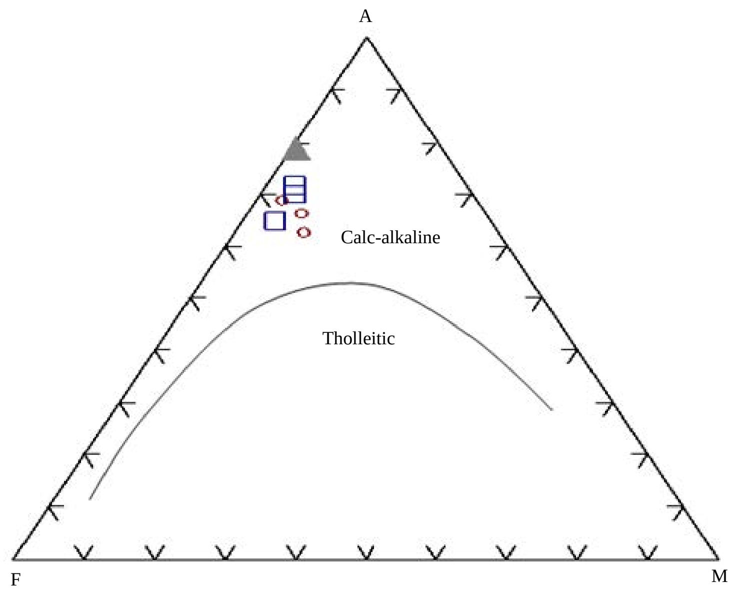

Fig. 6: AFM diagram confirming the calc-alkaline nature of the granitoids

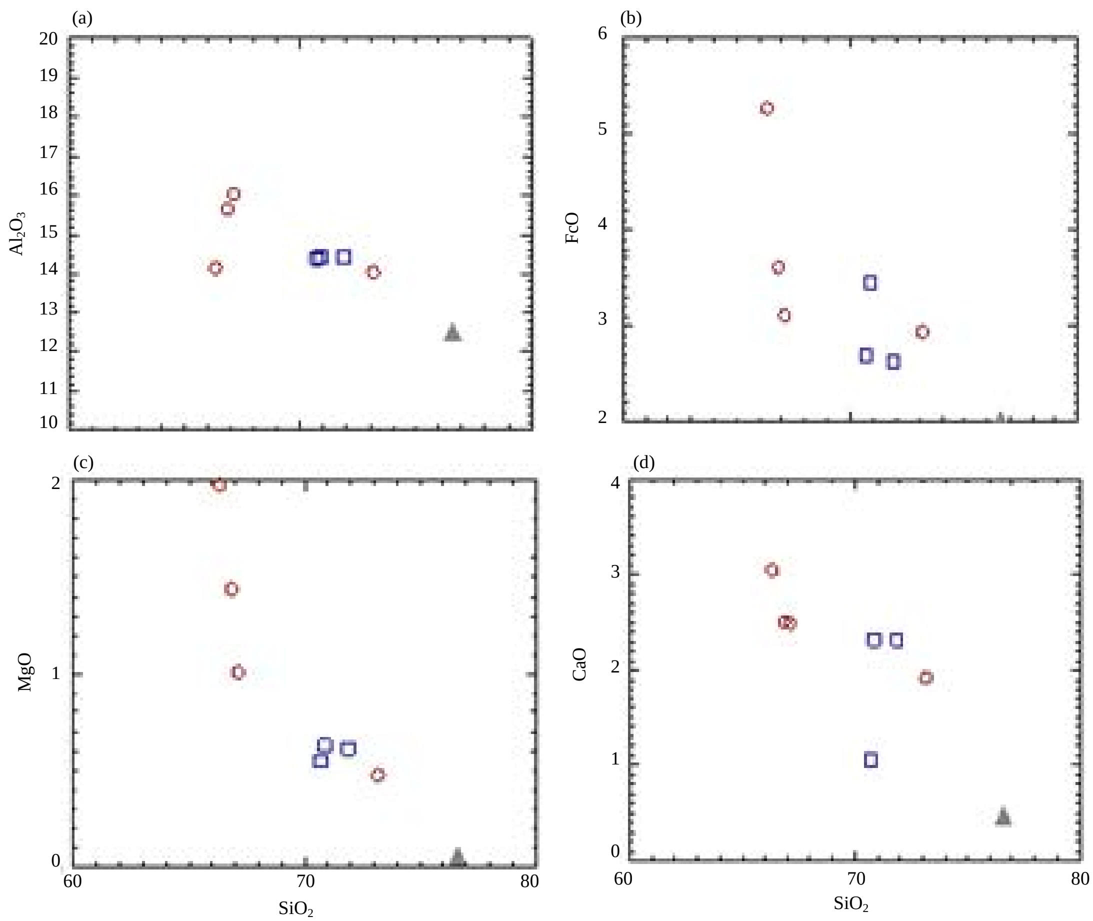

Fig. 7(a-f): Continue

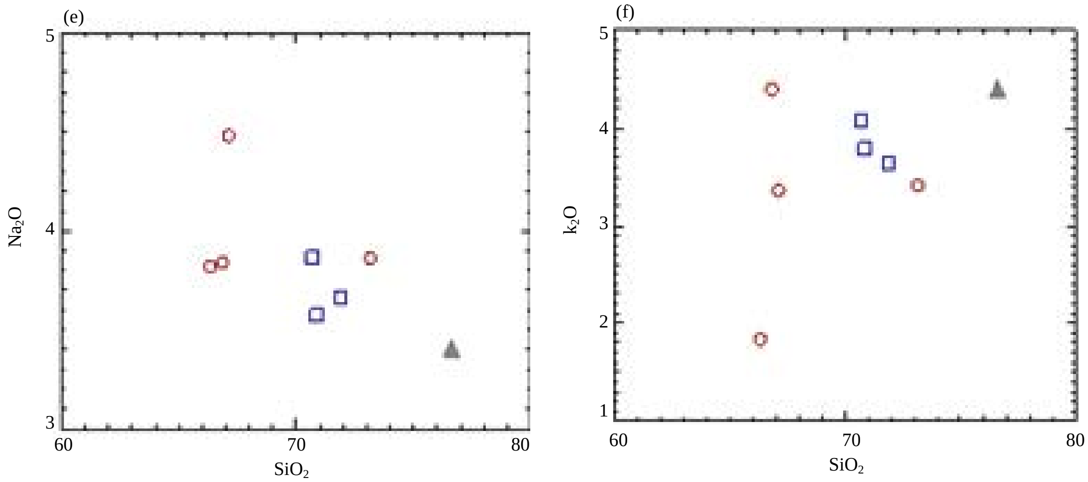

Fig. 7(a-f): Harker plots for major oxides of the granites studied

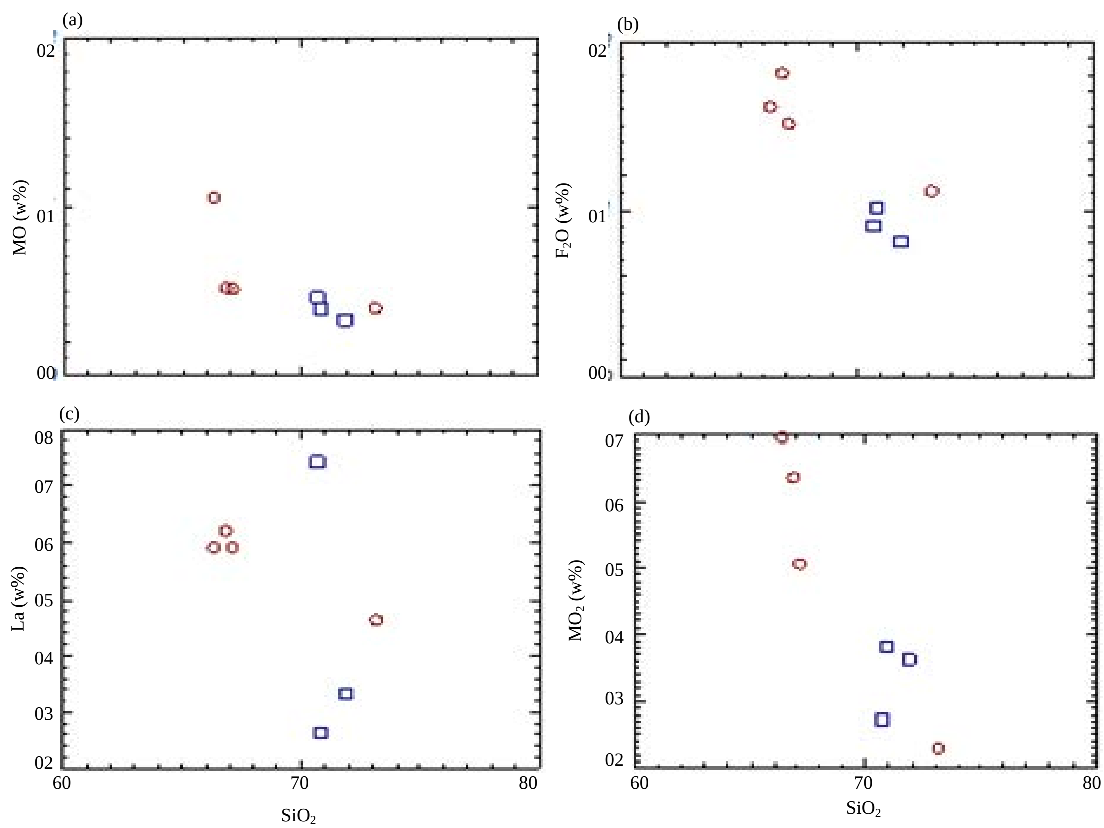

Fig. 8(a-d): Harker plots for the major oxides of the studied granites continue

The anorthite content of the feldspars in the granite range between 57.8 and 83.5% and averages 69.8625% while the average for the albite content is 29.175%. Far East of the area which is the eastern Nigerian basement terrain where the basement is essentially gneissic and little metasedimentry members, granitoids contrasts sharply with the Kakurigranitoids in that they plot as rift related granitoids (Ferre *et al.*, 2002). An attempt was made to use initial Pb-Pb whole rock isotopic data to assess the source for the granitoids. The samples were too few to generate an isochron but when compared with the data obtained from the other areas of the Kaduna region, the ratios are

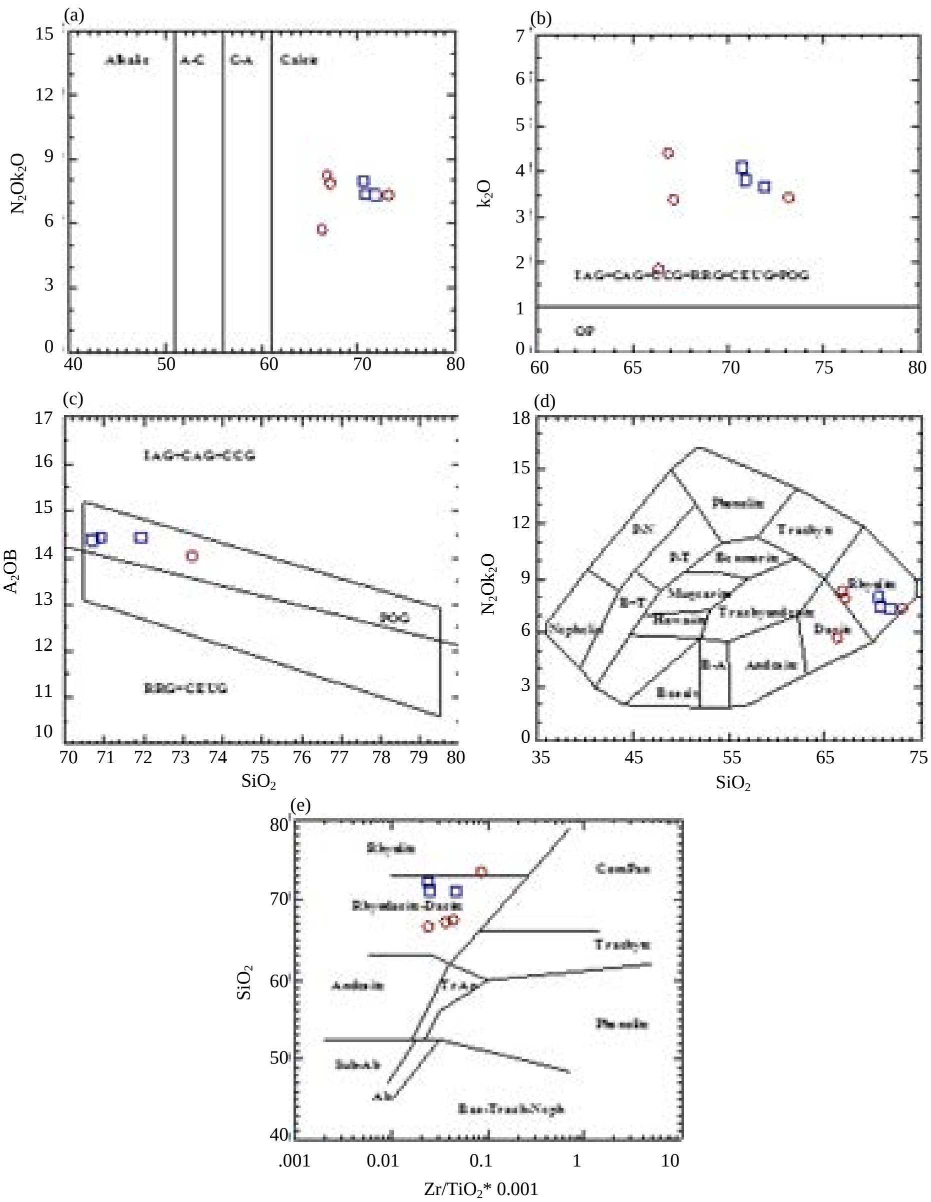

Fig. 9(a-e): Classification plot for oxides in the area

higher for Pb206/Pb204 (12.24) and Pb207/Pb204 (13.70) while the Pb content in the amphibolites are too low (4.2 ppm). The initial ratios were plotted on the same diagrams (Fig. 12) with granitoids from the eastern Nigerian terrain (Dada *et al*., 1995) and results show that the radiogenic Pb plotted in the plumbotectonic setting (Fig. 13) similar to the eastern terrains except that they are slightly more radiogenic and are likely to have emanated from the lower crust with contamination from upper crustal material during evolution which tallies with our inference from major and trace element data reported in the earlier section. Though transitional into the orogenic terrain and bearing in mind the fewness of our data, not precluding the comparison with the northern extension in Air-Niger which are of mantle origin, we may subscribe to the possibility of a much thicker crust earlier suggested by Dada *et al*. (1995) involved in our setting here. However, what is determinative is the source for our granitoids (Fig. 14).

It has been demonstrated that geochemical data can be used to test the tectonic setting of granite emplacement. The geochemistry of the granitoids is here considered very important both for the tectonic setting as well as possible mineralization of the basement rocks.

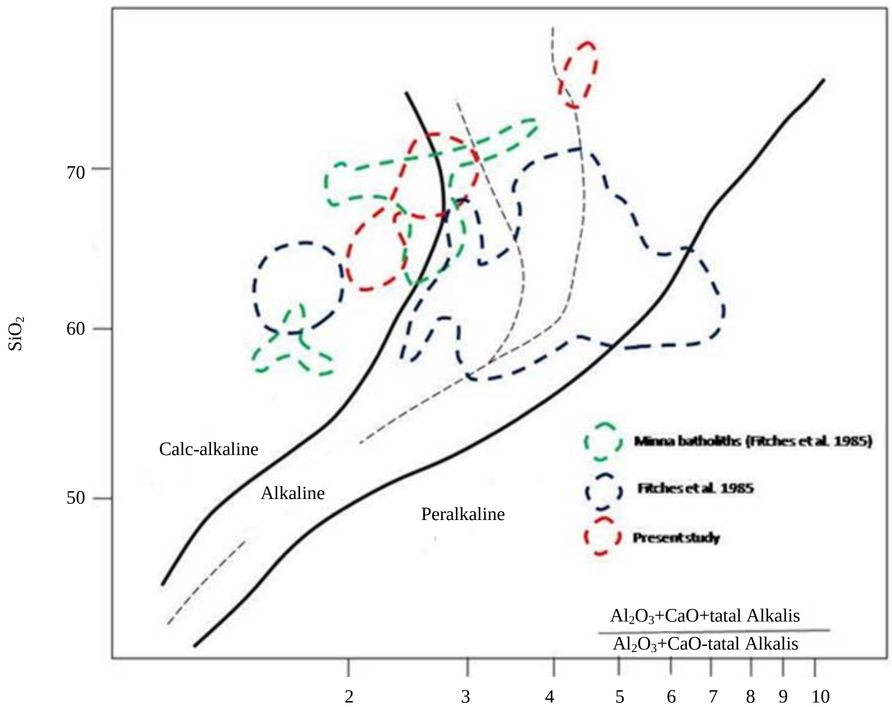

Fig. 10: Alkalinity Index plot after Wright 1969 showing the calc-alkaline to alkaline nature of the granitoids in the Kaduna area. The granitoids of northwestern area studied by Fitches *et al*. (1985) are plotted for comparison

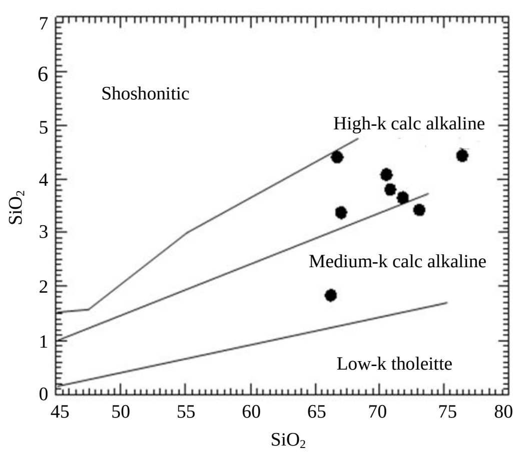

Fig. 11: SiO_2vs K_2O discrimination diagram showing the high calc alkaline composition for the granites

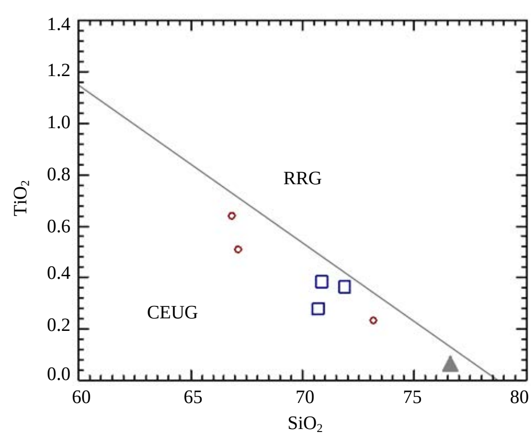

Fig. 12: The Continental epeirogenic uplift granitoids from the area

Generally, based on the major element variation discrimination diagrams, certain major conclusions were arrived at in other to determine the type for the granites as well as speculating their source. Harker plots of SiO_2 against most of the major oxides show that the granites were essentially from the same source but probably evolved and fractionated to result in the present rocks both within the texture as well as mineralogy.

As observed earlier, the granitoids plot as Continental Epeiorogenic Uplift Granitoids (CEUG) which contrasts with the far eastern Nigerian setting which behaves in a rift related granite setting (Ferre *et al*., 2002). This finding again tallies with the earlier observed structural break between the eastern and western Nigerian tectonic setting. This diagram of Maniar and Picoli (1989) best describes this setting because of the ambiguity inherent in the earlier

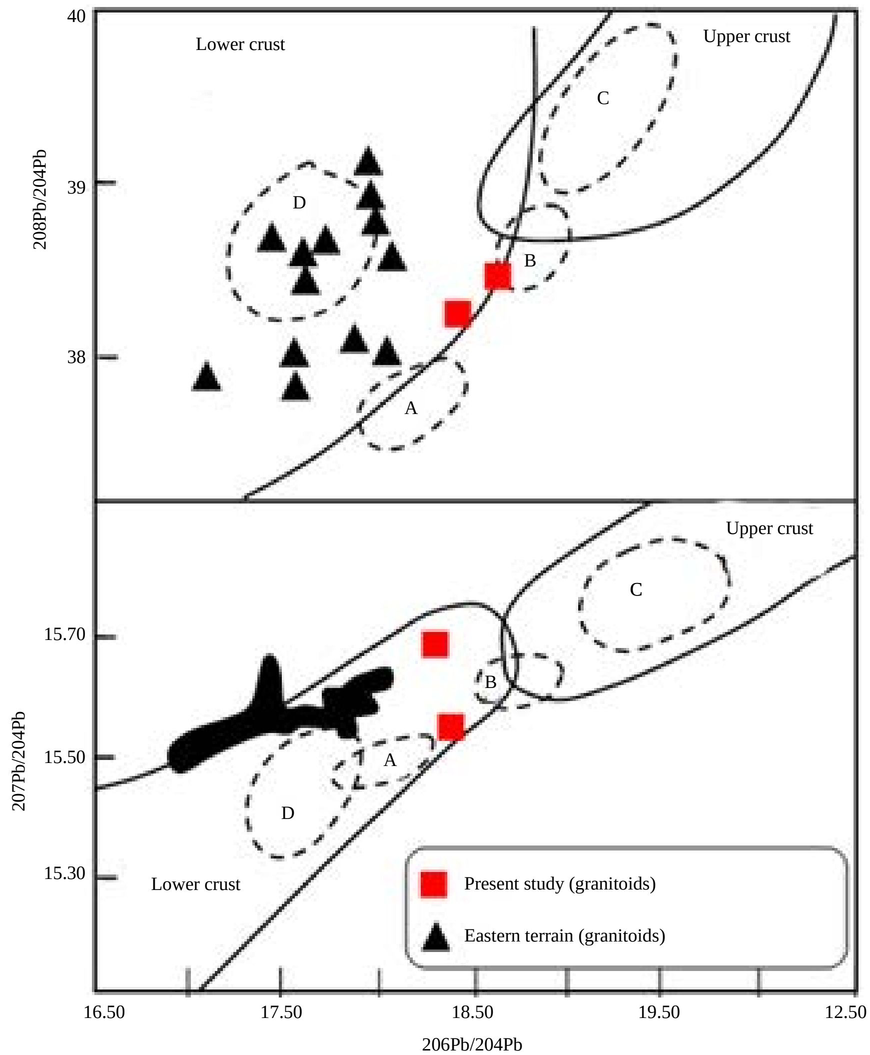

Fig. 13: Plot of Pb isotopic compositions in the global geotectonic environments after Zartman and Doe (1981). Black shades and triangles are granitoids from Eastern terrain (Toro). A = Mantle; B = Orogen; C = Upper crust; D = Lower crust (Dada, 1995)

version of 1984 wherein granites of other tectonic settings will plot as well. If this study subscribe to the calc-alkaline affinity of the granites and their I-type nature then the setting is pointing towards a post-collisional transcurrent geological setting.

The tectonic significance of the studied granitoids becomes important when they are compared with other regions of Nigeria. The A-B discrimination diagram of Debon and Le Fort (1983) shows that they are mostly confined to metaluminous zone and the fields V and VI. This was confirmed by the presence of sphene in the petrography of the rocks. In comparison with the north eastern Madagali granitoids of north eastern Nigeria (Baba, 2008), those of north eastern Nigeria are transitional between metaluminous and peraluminous. In the Ghumchi, Mika and Kanawa regions of the same northeastern Nigeria, the same peraluminousity persist for the uranium hosted altered granites (Suh, 1997). Additionally, the A/NK vs A/CNK plot for the Chikun Gwagwada granitoids are strongly peraluminous which is in consonance with the Madagali granitoids while those of central Nigeria were found to be metaluminous (A/NK≈0.76-0.93) with high K-calc-alkaline affinities (Ferre *et al*., 2002). It is concluded that eastward of the western Nigerian transitional suture; the I-type plutonism persisted signifying the orogenic nature for the granites.

It has been observed that Geodynamic evolution of elongate plutons is often syntectonic and rounded ones generally post-tectonic (Ferre *et al*., 1997). While much of

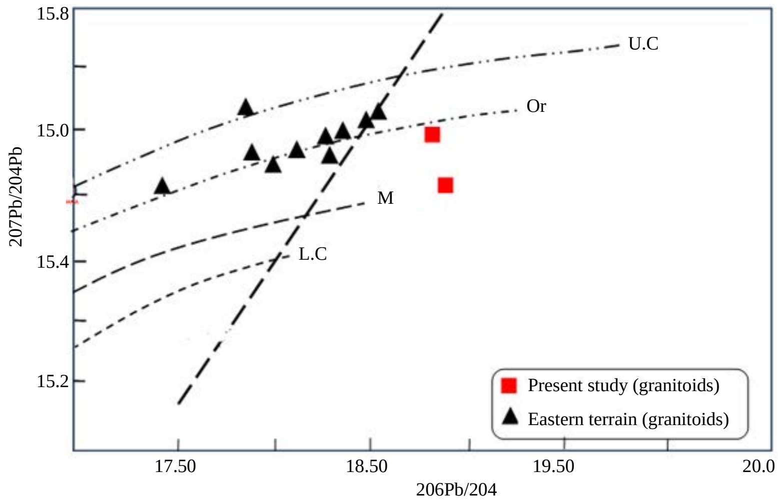

Fig. 14: Plot of initial Pb isotopic compositions in the global geotectonic curves environments after the plumbotectonic model of Zartman and Doe[21]. Black triangles are granitoids from Eastern terrain (Toro). M = Mantle; Or = Orogen; L.C. and U.C. = Lower and Upper Crust, respectively

the studies in western Nigeria have been relatively extensive and detailed, it is mostly concentrated on the North-South structural continuity of structures with remarkable correlative results. However, the lateral continuity eastward has not been systematic making the general geodynamic picture to be vague. Abaa (1991) proposed the following trends of metasomatic late stage reactions associated with gem formation in Nigerian basement granitoids:

- That if microscopically the feldspars affected are of albite-oligoclase content or plagioclase of higher anorthite content, then albite-oligoclase feldspars $+H^{+}+OH^{-}+F^{-}$ = fluorite+chlorite+topaz+quartz
- The presence of Be^{2+} could react with orthoclase feldspars to give beryl given the right conditions
- Albitization of basement granites to result in the release of Fe to from hematite by the reaction with plagioclase

The metasomatic conditions that affected the granitoids both from petrographic and normative classification as well as the feldspar classification diagrams shows that the anorthite contents are very low and they plot around the albite orthoclase axis. The orthoclase content slightly exceeds 50% while albite, anorthoclase and oligoclase content are high. This points to post emplacement sodic metasomatism or albitization of the rocks. The presence of beryl (tourmaline) associated with the late stage pegmatites emplaced in the granites could possibly be related to the sericitization of the orthoclase feldspars in the granites studied. This is petrographically evidenced by the mottled nature and alteration of the micas.

CONCLUSION

The major element geochemical signatures of the studied granites around Gwagwada central Nigeria point to an I-type Granitic geochemical affinity. Their evolutionary pattern give possible exploratory clues in the basement based on their petrographic and metasomatic post-emplacement histories.

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