Geochemical discrimination of newly discovered rare-metal bearing and barren pegmatites in the Pan-African (600 ± 150 Ma) basement of northern Nigeria

I. Garba

This study reports some general field, petrographic and geochemical characteristics of the most notable of the newly discovered northern Nigerian pegmatites. The objective is to understand their setting and geochemical characteristics that can discriminate between rare-metal and barren pegmatites in the region.

The author is at the Department of Geology, Ahmadu Bello University, Samaru, Zaria, Nigeria (igarba@inet-global.comor igriruwai@yahoo.com).

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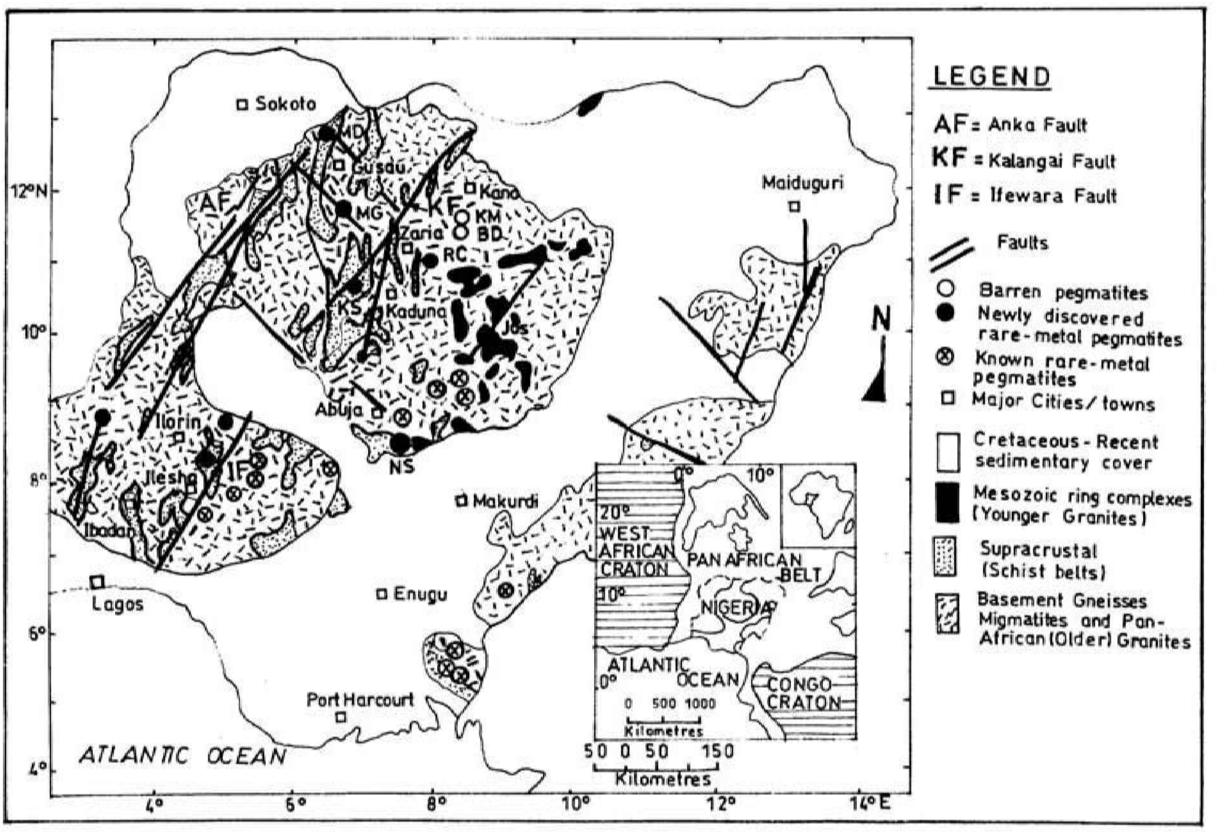
INTRODUCTION

Until recently, Pan-African rare-metal pegmatites in Nigeria were known mainly from a broad 400 km-long NE–SW trending belt stretching from the Wamba area (near the Jos Plateau) in central Nigeria to Ilesha area in south-western Nigeria, and few occurrences in the Obudu and Oban massifs of south-eastern Nigeria (Fig. 1).[9,10,16,17,27] Similar rare-metal pegmatites are known to continue into the north-eastern Brazil.[23,24] The Nigerian pegmatites were formed during the time span of 562–534 Ma,[20] indicating emplacement related to the end of the Pan-African magmatic activity, and have been sources of cassiterite and columbite–tantalite production since 1912, especially in central and south-west Nigeria.[16]

Since 1999, new rare-metal pegmatite fields have been discovered in the known belt and other areas, especially the Kushaka schist belt, the Magami and Maradun areas of the north-west and other areas of the south-west Nigeria (Fig. 1). The new discoveries were made by artisanal miners driven by the recent high price of columbite–tantalite concentrates. This



1 Regional geology of the Nigerian Pan-African basement, showing locations of areas of rare-metal and barren pegmatites (modified from the Geological Survey of Nigeria map, 1994). NS, Nassarawa; KS, Kushaka; MG, Magami; MD, Maradun; RC, Richifa; BD, Badafi; KM, Kafin Maiyaki

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development has shown that the rare-metal pegmatites in Nigeria are not restricted to the NE–SW belt. Widespread occurrences of semi-precious beryl, aquamarine and tourmaline are, however, known from many areas of the Nigerian Pan-African basement, associated with both the rare-metal and barren pegmatites.

REGIONAL GEOLOGY AND TECTONICS

The Nigerian Pan-African basement is part of an Upper Proterozoic-Lower Phanerozoic mobile belt situated between the West African and Congo cratons (Fig. 1). Three broad lithological groups are usually distinguished:

(i) A polymetamorphic gneiss-migmatite complex with ages ranging from Liberian (~2800 Ma) to Pan-African (~600 Ma). Metamorphism is generally in the amphibolite facies grade

(ii) The schist belts, which are mainly N–S to NNE–SSW trending belts of low grade (mainly greenschist facies) supracrustal (and minor volcanic) assemblages. They are considered to be Late Proterozoic cover infolded into the gneiss–migmatite complex. The schist belts are concentrated in the western half of Nigeria, and are seldom found east of 8°E longitude[2]

(iii) Syntectonic to late-tectonic Pan-African granitoids which intrude both the schist belts and the gneiss–migmatite complex. They comprise gabbros, charnockites, diorites, granodiorites, granites and syenites. The Pan-African granitoids in Nigeria are referred to as the Older Granites to distinguish them from Mesozoic anorogenic granite ring complexes (the Younger Granites).

The Nigerian schist belts are thought to have been deposited in back-arc basins which developed after the onset of subduction at the West African cratonic margin at about 1000 Ma.[14,26] Closure of the ocean at the cratonic margin at about 600 Ma led to deformation, metamorphism and emplacement of the Older Granites in Nigeria.[2,4] Uplift, acid volcanism and development of faults and shear zones were the last manifestations of the Pan-African event.[3,15,21] There is, however, increasing evidence to show that the Pan-African collision involved more of an aggregation of crustal blocks rather than between the West African craton and the Pan-African belt as a single entity.[1]

Two well-defined NE–SW (and NNE–SSW) trending fault systems (the Anka and Kalangai-Ifewara faults) cut and displace earlier N–S structures in the Nigerian Pan-African basement (Fig. 1). The scale of movement and displacement and the occurrences of

Table 1 Average trace and rare earth element geochemical data for the rare-metal and barren pegmatites and granitoids used in this study

Area	Nassarawa			Kushaka		Magami		Maradun	Richifa		Badafi	Kafin Maiyaki
Rock type	Rare-metal pegmatite	Barren pegmatite	Granitoid	Rare-metal pegmatite		Rare-metal pegmatite		Rare-metal pegmatite	Rare-metal pegmatite	Granitoid	Barren pegmatite	
Sample type	Whole rock			Whole rock	Muscovite	Whole rock	Lithium muscovite	Whole rock	Whole rock		Whole rock	
	(n = 3)	(n = 2)	(n = 1)	(n = 2)	(n = 3)	(n = 3)	(n = 3)	(n = 2)	(n = 2)	(n = 1)	(n = 4)	(n = 3)
K	44 205	23 071	37 925	59 391	81 688	6367	88 880	7100	55 519	41 245	1075	1167
Ba	7	22	1065	15	26	127	28	34	63	1510	31	84
Rb	2966	195	207	3580	3410	559	4000	1900	610	200	23	25
Sr	57	3	550	7	3	24	2	28	30	453	5	6
Zr	495	4	203	7	6	12	5	2	5	186	5	3
Ga	85	22	25	157	186	10	117	4	49	22	8	7
Cs	723	6	9	237	174	183	1000	1230	469	19	8	4
Li	…	…	…	…	…	1398	4550	2990	…	…	29	10
Be	24	6	5	88	387	343	54	2	12271	5	16	3
Nb	391	22	15	99	226	2	50	2	5	17	2	1
Ta	16 307	5	3	98	102	…	63	…	13	5	…	…
Sn	554	37	3	148	114	7	234	1	6	5	2	2
K:Ba	9823	1029	36	5105	4237	75	3174	209	881	27	35	14
K:Rb	14	118	183	17	25	12	22	4	91	206	47	47
Rb:Sr	687	56	0·4	597	1372	49	2000	68	20	0·4	5	4
La	0·2	1	47	0·9	1·3	32	1·1	4·2	5·4	40	12	6
Ce	0·3	2	85	0·4	1·1	52	1·5	4·8	2·2	75	82	25
Nd	0·1	1	33	0·6	1·2	45	2·5	4·3	4·1	30	16	7
Sm	0·1	0·3	6	0·1	0·2	15	0·9	0·8	0·9	5	4	2
Eu	0·05	0·01	1·3	0·05	0·06	1·2	0·1	0·2	0·3	1·4	0·3	0·3
Tb	0·1	…	0·5	0·1	0·1	2·9	0·3	0·1	0·3	0·8	0·5	0·3
Yb	0·1	0·3	0·8	0·01	0·1	3·3	0·6	0·1	1·1	2·1	1·9	0·6
Lu	0·04	0·04	0·1	0·04	0·03	0·4	0·1	0·1	0·15	0·3	0·2	0·1

All values, except the ratios, are in ppm. The complete data list is available from the author on request.

felsic–mafic–ultramafic rocks along these faults suggest that they might be crustal sutures of the Pan-African collision.[1,21,28]

FIELD AND PETROGRAPHIC CHARACTERISTICS OF THE PEGMATITES

Rare-metal pegmatites

Five areas of the newly discovered rare-metal pegmatites have been studied – Nassarawa and Richifa in central Nigeria and Kushaka, Magami and Maradun in the north-west (Fig. 1). In most of these areas, there are more than a dozen *en echelon* series of dykes, sills and irregular pegmatite bodies usually forming prominent ridges. Most of the pegmatite bodies seldom exceed 200–300 m in length, 1–2 m wide, and suffer variable degrees of tropical weathering. The host rocks include gneisses–migmatites (Kushaka, Magami), schists (Nassarawa, Kushaka, Maradun) and granitoids (Richifa). Although the pegmatites have sharp contacts with their host rocks, wall rock alteration (of mostly tourmalinisation) is a common phenomenon. Another common feature of the rare-metal pegmatites is their close proximity to major and subsidiary fault structures (Fig. 1).

The pegmatites comprise quartz, K-feldspar (mostly microcline perthites), plagioclase, mica (muscovite ± biotite) and minor tourmaline (schorl) and occasionally beryl, lepidolite and spodumene. Late-stage albite and sericite are also commonly observed in the rare-metal pegmatites. Mineralisation is in the form of dissemination and discrete concentrations of columbite–tantalite accompanied by cassiterite, ilmenite, Fe-oxides and occasionally bismuthinite and fluorite. The mineralisation is observed to have accompanied late-stage albitisation. Ore grades are very variable between and even within deposits, generally ranging from < 100 ppm to > 10% (Nb + Ta). More than 500 t of columbite–tantalite concentrates have been produced from these pegmatites since their discovery.

Barren pegmatites

Pegmatite bodies, barren of rare-metal mineralisation, are ubiquitous in the Nigerian Pan-African basement. They are found associated with all the major lithologies of the basement, i.e. gneisess, migmatites, schists and granitoids. The morphology and major mineral composition (quartz–feldspar–mica) are mostly not different from those of the rare-metal types.

Pegmatites, apparently barren of rare-metal mineralisation, are found associated with gneisses–migmatites of Badafi and Kafin Maiyaki north-east of the Richifa area of rare-metal pegmatites (Fig. 1). Similar barren pegmatites, but closely associated with a Pan-African granitoid intrusion, are known in the Nassarawa area of rare-metal pegmatites (Fig. 1). In the Badafi and Kafin Maiyaki areas, the pegmatites are dykes and lenses occurring in conformity with the regional foliation trend of their host gneisses and migmatites. The mineralogy consists of quartz, K-feldspar, plagioclase, muscovite and occasionally biotite, and beryl. Some concentrations of pyrite are also noticeable in few locations. They suffer variable degree of weathering, ranging from relatively fresh outcrops to intensely lateritised bodies. The Nassarawa granitic (barren) pegmatites form extensive outcrops often replacing the granitoid intrusion in its outermost part. Some are dykes intruding the host granite and surrounding gneisses and schists. They comprise mostly of quartz, K-feldspar, plagioclase, muscovite and widespread black tourmaline (schorl).

GEOCHEMICAL CHARACTERISTICS AND DISCRIMINATION OF THE PEGMATITES

Samples and analysis

A total of 29 representative whole rock and muscovite samples of the pegmatites and granitoids were used for this study (Table 1). Major, trace and rare-earth elements were determined, using lithium metaborate/tetraborate fusion, inductively-coupled atomic emission spectrophotometry (ICP-AES) and an inductively coupled plasma-mass spectrometry (ICP-MS) technique developed by Activation Laboratories Ltd (ACTLABS) Ancaster, Ontario, Canada. However, only the average values of the trace and rare-earth element data are reported and used in this study (Table 1).

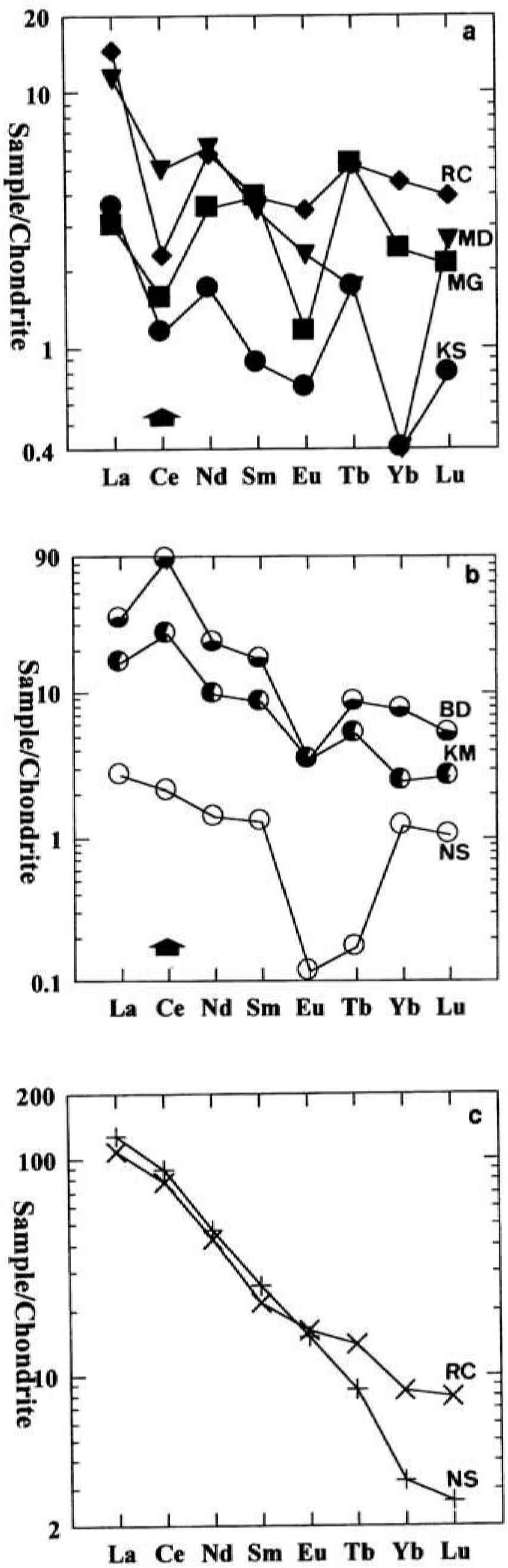
Trace and rare-earth elements

There appears to be a marked difference in trace element and rare-earth element concentration and fractionation patterns between the rare-metal and barren pegmatites (Table 1). Of great significance is the distinct enrichment of Rb, Cs and in many, Ga, Nb, Ta, Sn, Li and Be in the rare-metal pegmatites relative to the barren types and the Pan-African granitoids. The barren pegmatites are also distinguished according to their origin (i.e. metamorphic and granitic) by the higher K:Ba ratios of the latter. The high K:Ba and Rb:Sr but low K:Rb ratios of the rare-metal pegmatites attest to their granitic origin. The Pan-African granitoids (of Nassarawa and Richifa) show a remarkable similarity in chemical composition despite their wide distances of location (Figs. 1 and 2, Table 1). The rare-earth element pattern of the granitoids shows a calc–alkaline trend, similar to those reported from other areas of the Nigerian Pan-African basement.[11]

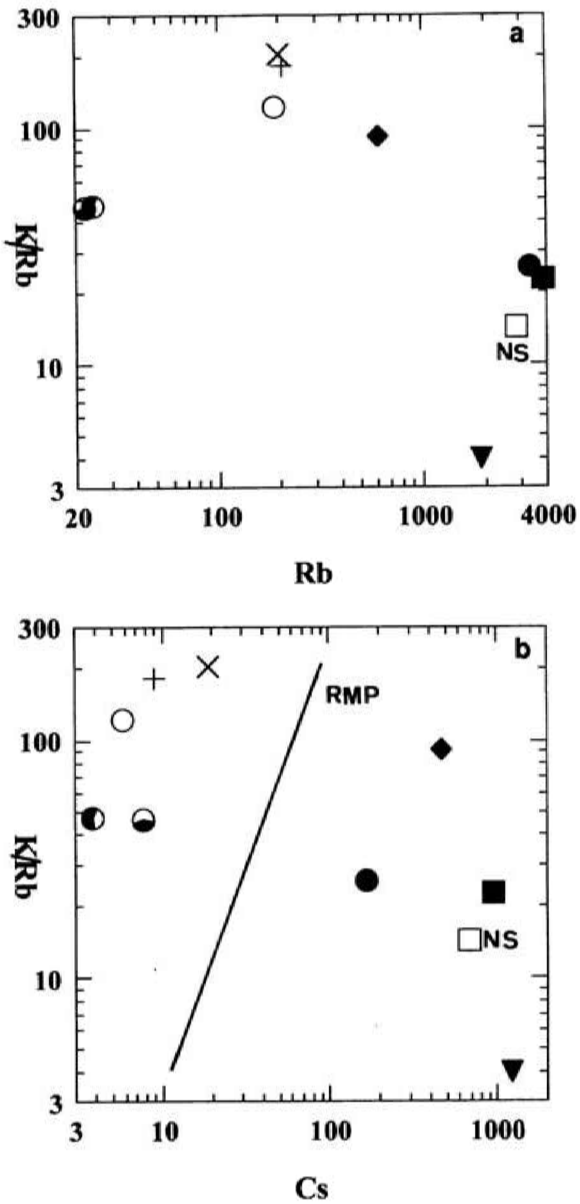
The rare-earth element fractionation trends of the pegmatites show a close similarity within the two groups, essentially defined by a negative Ce anomaly in the rare-metal pegmatites and a positive Ce anomaly or lack of it in the barren types, depending on their respective origin (Fig. 2).

DISCUSSION

Extreme fractionation of lithophile elements such as Rb and Cs is a common geochemical feature of granitic pegmatites, especially the rare-metal bearing types.[7] Late-stage progressive fractional crystallisation leads to decrease in K:Rb ratios and increase in K:Ba



2 **Rare-earth element chondrite-normalised plots for rare-metal pegmatites, barren pegmatites and Pan-African granitoids from the study areas. (*a*) Rare-metal pegmatites: KS, Kushaka; MG, Magami; MD, Maradun; RC, Richifa. (*b*) Barren pegmatites: NS, Nassarawa; BD, Badafi; KM, Kafin Maiyaki. (*c*) Pan-African granitoids: NS, Nassarawa; RC, Richifa**



3 **Discrimination diagrams showing the degree of fractionation and mineralisation of the pegmatites: (a) K:Rb vs Rb, (b) K:Rb vs Cs. The discrimination line in (b) separates the field of rare-metal pegmatites (RMP) from the barren class. It is adapted from Černý[5,6] and Morteani *et al.*[23] Plot symbols are the same as in Figure 2.**

and Rb:Sr ratios. These trends are noticeable in the compositional trends of the granitic pegmatites when compared to the ratios in the Pan-African granitoids in the Nassarawa and Richifa areas (Table 1). K:Rb versus Rb and K:Rb versus Cs diagrams (Fig. 3) suggest that the barren metamorphic pegmatites of the Badafi and Kafin Maiyaki areas and the granitic (barren) Nassarawa pegmatites are relatively unfractionated ('primitive') when compared with the rare-metal pegmatites. While Rb is an indicator of the degree of fractionation in the granitic pegmatites, Cs appears to be the most important discriminator of the rare-metal pegmatites (Fig. 3*b*). The rare-metal pegmatites generally show extreme fractionation, except those of Richifa which show a lesser degree of fractionation, a possible reason for their relatively low degree of rare-metal mineralisation.

The geochemical characteristics of the rare-metal pegmatites of the Magami area which are hosted by gneisses and migmatites are unlike those of metamorphic origin, such as the barren pegmatites of the Badafi and Kafin Maiyaki areas (Table 1). Rather, they appear to be highly fractionated granitic pegmatites. Similarly, the rare-metal pegmatites of Nassarawa are evidently not co-genetic to the nearby granitoid that host the barren pegmatites. They are highly fractionated granitic pegmatites of probably remote origin.

The negative Ce anomaly of the rare-metal pegmatites is taken to be an indication of oxidising conditions[8,13,25] during rare-metal mineralisation, which possibly involved interaction between magmatic melt-fluids and host rocks over great distances. The observed wall rock alteration phenomenon associated with the rare-metal pegmatites is a further indication of the role of fluid processes in their emplacement. The role of fluid phases along continental lineaments have been speculated to be important in the genesis of rare-metal pegmatites.[9,17–20,22,27] The relationship between rare-metal (pegmatite) mineralisation and late Pan-African tectonics have also been demonstrated in the Kushaka schist belt by Garba.[12]

CONCLUSIONS

The study has shown that rare-metal pegmatites in the Pan-African terrain of northern Nigeria can be distinguished from the barren ones by enrichment of Rb and Cs, while Ga, Be and Li concentrations are variable. The pegmatites can also be classified into barren and rare-metal types by K:Rb versus Cs fractionation trends while their K:Rb versus Rb trends can demonstrate their degree of fractionation. Chondrite-normalised rare-earth element plots also distinguished the rare-metal pegmatites by their negative Ce anomaly, which is an indication of oxidation due to the influence of fluid-rock metasomatic processes in their genesis.

The rare-metal pegmatites are found to have extreme fractionation, while the barren pegmatites show little fractionation, related to proximity to their parental melt sources. The barren pegmatites are found to be of possible metamorphic origin in high-grade rocks and those in close proximity to their parental granitic rocks, whereas the rare-metal pegmatites have remote sources of their igneous melts, which also had sufficient time to fractionate.

Evidence from field setting, degree of fractionation and influence of fluid phases in the genesis of rare-metal pegmatites in the Pan-African basement of northern Nigeria all point to the key role played by continental fault lineaments in generating second-order pathways (dilations) for pegmatite melts and fluids.

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Author

I. Garba graduated with the degrees of BSc Geology (1980) and MSc Mineral Exploration (1985) from Ahmadu Bello University, Zaria, Nigeria and PhD and DIC in Mineral Deposit Studies from Imperial College of Science, Technology & Medicine, London, UK (1993). He is currently a Senior Lecturer at the Department of Geology, Ahmadu Bello University, Zaria, Nigeria.