Petrogenesis and geotectonic setting of the Pan-African basement rocks in Bamenda Massif, Obudu Plateau, southeastern Nigeria: Evidence from trace element geochemistry

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Abstract The rocks of the Obudu Plateau range from high-grade metagreywacke-pelite sequence to metaigneous (granitic to tholeiitic) and polymagmatic (calc-alkaline granitic to olivine tholeiitic) igneous rocks. Several co-variance diagrams and other parameters indicate that the trace elements of rocks in southern Obudu Plateau exhibit systematic variations and suggest highly heterogeneous protoliths. The tectonic setting of the rocks indicates rifting and collisional to non-orogenic emplacements in oceanic to ensialic environments. The calc-alkaline and tholeiitic nature of the magmatism as well as the greywacke-pelite sequence is suggestive of an Andean-type continental environment.

Key words trace element; Pan-African; petrogenesis; geotectonic; Obudu Plateau

1 Introduction

The study area is part of the Obudu Plateau, which forms part of the Precambrian Pan-African tectonothermal belt, lying between the West African Craton and the Gabon-Congo Craton (Fig. 1). It is bounded by the Benue Trough, in the NE-SW axis, and the Cameroon Volcanic Line in the southeast, and represents the extension of the Bamenda Massif of Cameroon into southeastern Nigeria (Orajaka, 1964; Umeji, 1991; Ekwueme, 1990a, 1994, 1998; Ejimofor et al., 1996). It is composed predominantly of a continuous N-S (0°-30°) highly deformed metamorphic belt composed of migmatites, gneisses and paraschists, intruded by plutons of enderbites, charnockites, stocks of granites and gabbros as well as dykes of pegmatites, aplites, dolerites and quartz veins. In this paper, we make a pioneer attempt to infer tectonic models of the rocks of the Obudu Plateau in terms of the geochemical behaviour of the trace elements.

2 Geological setting

The Obudu Plateau forms the western extension of the Bamenda Massif of Cameroon into southeastern Nigeria. It is a Precambrian basement belt, which was affected by the Pan-African event. This event resulted in a belt of metamorphic rocks ranging from high-grade metagreywacke-pelite sequence to metaigneous (granitic to tholeiitic) rocks and Pan-African structurally controlled polymagmatic (calc-alkaline granitic to olivine tholeiitic) igneous rocks of crustal to mantle origin, which include enderbites, charnockites, granites, gabbros, pegmatites, aplites and dolerites in intrusive relation with these Pan-African metamorphosed rocks.

3 Method of analysis and results

Inductively Coupled Plasma Mass Spectrometer (ICP-MS) technique (fusion dissolution methods) was employed to analyze the selected samples of gneiss, schist, granite, charnockite and dolerite from southern Obudu Plateau.

The trace element compositions of the analyzed rock samples are presented in Table 1, where samples are grouped according to their petrologic type. Table 2 presents the average composition of trace elements in the rocks studied. Results of the analysis showed that the paragneisses have high values of Zr (215×10^{-6} – 324×10^{-6}) (Table 1) compared to greywackes (140×10^{-6}), and shales (160×10^{-6}) (Taylor, 1965). Also the orthogneisses have variable values (74×10^{-6} – 196×10^{-6}) compared to granites (180×10^{-6}) (Taylor, 1964). This variability has also been recorded in granites from Kabba-Lokoja in central Nigeria (Ezepue and Odigi, 1993). Average Ba content (576

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$\times 10^{-6}$) in the paragneisses is higher than that of greywackes and shales while the orthogneisses have lower values (411.3×10^{-6}) than granites (600×10^{-6}) (Taylor, 1964) (Table 3). In general, the gneisses are rich in W, Co and Sc and poor in LILE, while As, Mo, Ag, In, Sn, Sb, Bi and Ni are absent. The contents of W (317.2×10^{-6} – 358.3×10^{-6}) in the gneisses are exceptionably high, and indeed in all the rocks compared to the average content of basaltic and granitic rocks (Taylor, 1964).

The paragneisses also have high V, Cu, Hf and Cr, low Y, Be, Zn, Ge, Cs, Ta, Th and U, and a normal content of Ga. Comparatively, the orthogneisses have high Zn and U, low Y, Be, Cu, Cs, Ta and Th, and normal contents of Ga, Ge and Hf, and are absent in Cr (Tables 1 and 2). The values of Ni and Zn in the orthogneisses contrast with those obtained for hornblende gneisses in the Ilesha area (Olade and Elueze, 1979) and hornblende gneisses in the Igara area of southern Nigeria (Okeke and Meju, 1985). A distinctive feature of the gneisses is that the paragneisses are higher in trace element concentrations, except LILE, Zn, Pb and U, than the orthogneisses (Tables 1 and 2). The schists have high contents of Sc, V, Cr, Co, Ni, Zn and W, normal contents of Ga, Ge, Cs, and Hf, low contents of LILE, Be, Cn, Sn, Ta, Pb and U, and no As, Mo, Ag, In, Sn, Sb and Bi (Table 1). The schists and gneisses share identical characteristics in their trace element concentrations of Sc, V, Cr, and Co.

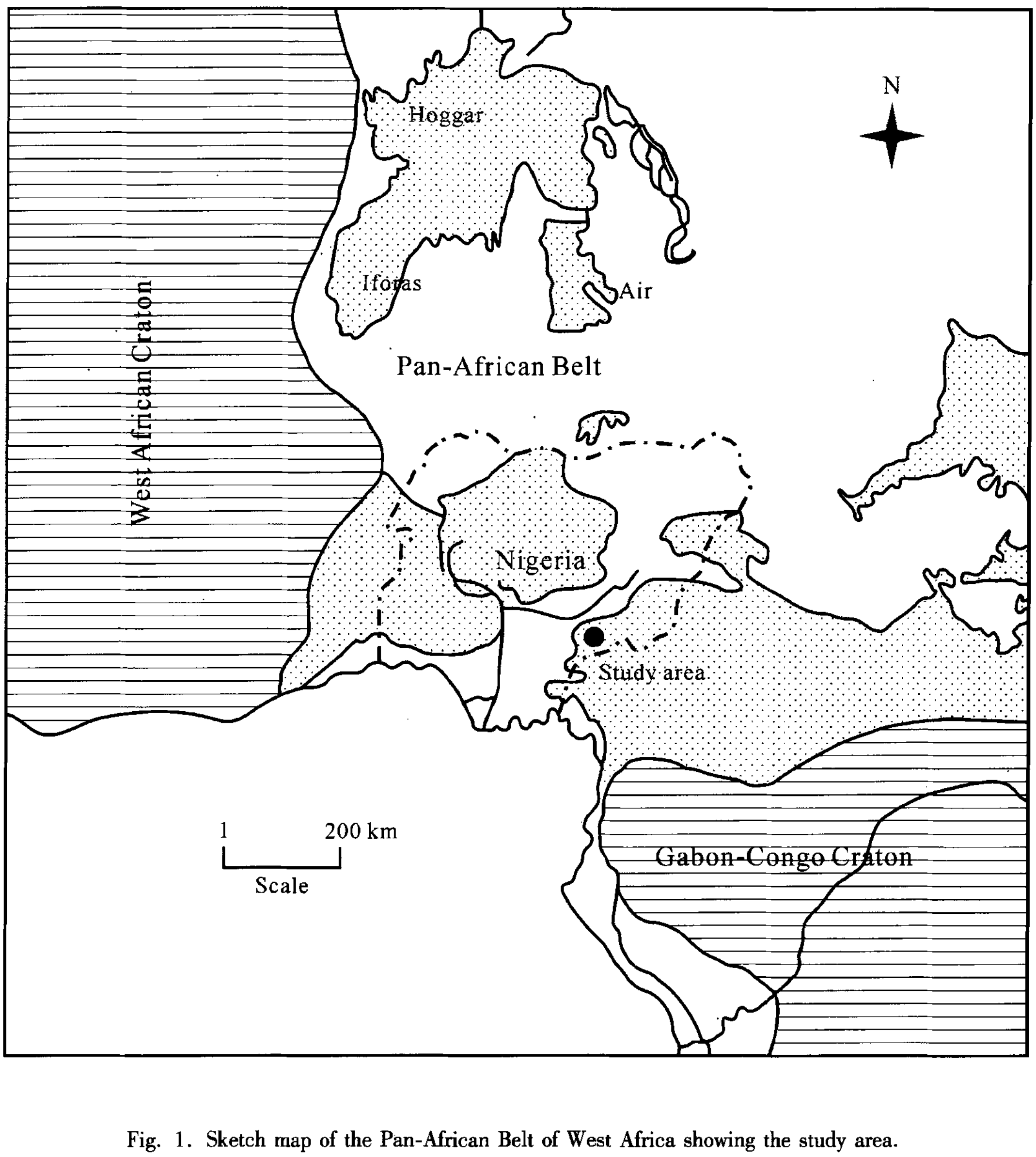

Fig. 1. Sketch map of the Pan-African Belt of West Africa showing the study area.

Table 1. Trace element compositions of the igneous and metamorphic rocks of southern Obudu Plateau

	Sc	Dl	OGn	PGn	Ch	Gr	Ch	Ch	Gr	OGn	Gr	OGn	PGn	Sc	Sc	Dl	PGn
V	132	320	66	-5	63	31	9	8	16	48	18	63	96	187	63	336	12
Cr	100	-20	69	-20	-20	-20	-20	-20	-20	32	-20	80	68	125	72	-20	-20
Co	63	50	62	47	43	52	45	43	49	61	48	81	70	66	57	51	54
Ni	47	49	-20	-20	-20	-20	-20	-20	39	-20	-20	27	35	86	38	98	-20
Cu	21	26	27	-10	17	-10	13	16	34	12	-10	53	30	39	-10	39	10
Zn	94	144	38	-30	90	59	68	82	34	94	-30	74	40	138	109	150	-30
Ga	20	25	15	23	20	26	25	26	23	21	18	19	20	25	23	26	20
Ge	1	1	2	1	1	-1	1	1	1	1	-1	2	-1	2	1	1	-1
As	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5
Rb	93	25	65	185	22	167	98	96	273	97	207	74	103	119	138	38	37
Sr	356	389	177	89	978	287	493	484	173	199	167	345	177	220	231	369	446
Y	32	43	15	5	30	14	26	26	14	23	16	49	25	37	14	41	2
Zr	210	303	262	74	574	582	673	604	477	196	284	324	215	214	91	318	137
Nb	8	30	11	9	15	12	18	17	18	9	9	8	6	11	7	34	5
Mo	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	2	-2
Ag	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
In	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
Sn	1	2	-1	-1	-1	-1	-1	-1	3	1	-1	-1	-1	2	2	2	-1
Sb	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
Cs	4.7	-0.5	1.6	-0.5	-0.5	1.8	0.8	0.8	1.8	2.0	1.0	0.6	1.3	6.5	5.0	-0.5	-0.5
Ba	685	403	460	420	2020	1860	3530	3380	1230	396	892	602	763	704	338	377	418
Hf	6.0	7.6	6.8	2.7	11.4	15.7	15.7	14.2	13.9	5.7	8.8	9.7	6.2	6.2	2.5	7.7	4.2
Ta	1.1	2.7	1.1	0.8	1.2	1.0	1.5	1.5	1.5	1.1	1.1	1.1	1.1	1.5	0.9	2.7	0.7
W	281	82	305	323	119	288	254	252	251	323	315	414	356	250	261	97	307
Ti	0.7	-0.1	0.3	1.3	0.1	1.0	0.5	0.6	1.2	0.5	0.3	0.5	0.5	0.8	1.1	0.2	0.2
Pb	10	-5	-5	29	-5	24	16	22	16	7	-5	13	10	10	11	-5	-5
Bi	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
Th	19.0	9.6	12.4	19.5	2.7	84.0	5.3	4.7	93.2	19.4	90.2	6.3	15.0	11.9	1.6	5.5	2.9
U	2.0	1.1	0.7	4.2	0.2	3.0	1.0	1.0	4.9	2.4	2.9	0.7	1.7	2.2	0.9	1.1	0.3
Sc	21	26	11	2	21	5	11	8	2	11	4	22	11	27	12	27	3
Be	1	2	2	-1	2	1	1	1	2	1	2	-1	3	2	2	2	1

OGn. Orthogneiss; PGn. paragneiss; Sc. schist; Gr. granite; Ch. charnockite; Dl. dolerite.

Table 2. Average trace element compositions of the metamorphic and igneous rocks from southern Obudu Plateau

Element ($\times 10^{-6}$)	Schist	Paragneiss	Orthogneiss	Total gneiss	Dolerite	Charnockite	Granite
Ba	575.7	576	411.3	493.7	392	2878	1327.3
Sr	269	233	244.7	238.8	379	651	209
Y	27.7	29.7	10.0	32.3	42	26.3	14.7
Sc	20	14.7	5.3	10	26.5	10.2	3.7
Zr	171.7	267	131.3	201	310.5	574	447.7
Be	1.7	1.3	0.3	0.8	2	1.3	1.7
V	127.3	75	18.3	46.7	328	22	21.7
Cr	99	72.3	-0.3	11.8	-20	-7	-20
Co	62	71	54	62.5	50.5	43.7	49.7
Ni	57	14	-20	-3.0	73.5	-20	-0.3
Cu	3.8	36.7	4	20.3	32.5	15.3	4.7
Zn	113.7	50.7	11.3	31	147	80	21
Ga	22.7	18	21.3	19.7	25.5	23.6	22.3
Ge	1.3	1.7	0.3	0.7	1	1	-0.3
Rb	116.7	80.7	106.3	93.5	31.5	72	215
Nb	8.7	6.25	7.7	8	32	121.7	13
Cs	5.4	1.2	0.3	0.75	3.2	0.4	1.5
Hf	4.9	7.6	4.2	5.9	4.1	13.8	12.8
Ta	1.17	1.1	0.9	0.983	1.0	1.4	1.2
W	264	358.3	317.7	338	164	208.3	284.7
Tl	0.867	0.433	0.7	0.55	0.35	0.4	0.8
Pb	10.3	6	10.3	8.2	2.5	11	11.7
Th	10.8	11.2	13.9	12.6	6.8	4.2	89.1
U	1.7	1.0	6.9	2.1	1.3	0.7	3.6

Table 3. Comparative trace element geochemistry of the granites of southern Obudu Plateau with the averages of some other Pan-African granites and granites in the other parts of the world

Element	Av. for granites (Taylor, 1965)	Av. for monzogranites, Jato Aka (Umeji, 1991)	Av. for potassic porphyritic granites, Igbeti (Rahaman et al, 1983)	Av. for granite, Obudu Plateau (this study)
Sr	100	287	210	209
Rb	150	104	210	216
Zr	180	854 - 1128	380	448
Ba		2105	448 - 1202 av. 852.33	1327
Y	40	58	46	145
Rb/Sr		0.249 - 0.442	0.622 - 1.44	0.58 - 1.58
K/Rb		400-591	150-300	189-242

The Obudu Plateau granites are high in the trace elements LILE, Co, Hf, W and low in Be, Ni, Cu, Zn, Be, Sn, Ta, Cs, Pb and U. The charnockites are high in Sc, V, Cu, Zr and Sr, and low in Y, Ta, Pb, Be, Rb and Th (Tables 1 and 2) relative to the average abundance of the elements in granites (Taylor, 1964). The trace element concentrations of granites in the study area are variable with the average values for Jato Aka monzogranites (Umeji, 1991) and for granites in general (Taylor, 1965) (Table 3). The trace element concentrations are, however, identical to the average values for the potassic porphyritic granites of Igbeti in Southwest Nigeria (Rahaman et al., 1983). The charnockites have contrasting trace element abundances with those of Ado-Ekiti and Akure, SW Nigeria, with lower V, Cr, Ni, Sr, Y and Nb and higher Ba concentrations. The charnockites also contrast with the Oban Massif, having lower Sr, Ni, and Cr, and higher Rb and Ba contents.

The contents of Sr decrease while increasing Rb in granites with increasing SiO_2 content. The average Sr content of 564.5×10^{-6} for the charnockites is far excessive over the value for the enderbites of the Obudu Plateau (Orajaka, 1971), potassic porphyritic granites from Jato Aka (Umeji, 1991) and the average for granites (Taylor, 1965). The average Rb content and Rb/Sr ratio of the charnockites are very low compared to the values obtained for the granites of Jato Aka, Igbeti and southern Obudu Plateau. The average Zr content (576×10^{-6}) of the charnockites follows the same geochemical trend, except that it is lower than the value for granites from Jato Aka.

The range of Ba contents of the charnockites shows a great contrast with granites of the study area, and those of Igbeti, but comparable to the values for Jato Aka granites and enderbites of the Obudu Plateau. The average Y content of these charnockites is lower than the values for the granites of Jato Aka and Igbeti, enderbites of the Obudu Plateau and the average for granites (Table 3). However, it is higher than the values for the granites of southern Obudu Plateau. The charnockites have distinctive geochemical features with respect to the granites. They are particularly rich in Ba and Sr, and richer in Y and Sc than the granites and poor in Th and U (Tables 1 and 2). Rb/Sr ratios in charnockites are 0.02 - 0.20 and 0.58 - 1.58 for granites. LILE, W, Tl, Pb, Th and U are high in the granites, whereas Sr, Y, Sc, V and Zn are low. Ba, Sr, Zr Ni and Zn values are high in the charnockitic rocks while Pb is low. In general, the charnockites have higher Ba, Sr, Y, Sc, Zr, Cu, Zn, and Pb and lower Be, V, Rb and Th contents than the granites. The dolerites of the study area have high concentrations of Ba, Y, Zr, Be, V, Ga, Nb, Mo, Cs, Hf, W and Th, and normal concentrations of Co, Ge, Rb, Sn, Ta and U. They also have low concentrations of Sr, Sc, Ni, Cu, Zn and Pb, and contain no Cr, As, Ag, In, Sb and Bi (Table 1).

4 Petrogenesis

Interpretation of the geochemical data is based mainly on the chemical variations and comparisons with the published analyses of similar rocks from other parts of the world. The essence is to discriminate the primary characteristics of the rocks, with respect to their petrogenesis and tectonic settings. Analysis of the trace element data of the rocks indicates a wide range of relationships in their protoliths, evolution and tectonic setting.

The range of K and Rb contents suggests that the protoliths of the orthogneisses had intermediate to acid compositions with higher sodic feldspar contents of the protoliths, based on the average contents of Ba (411.3×10^{-6}) and Sr (244.7×10^{-6}). The low Y/Nd ratio indicates calc-alkaline nature of the biotite hornblende gneisses (orthogneisses). The low Ni and Cr contents in the orthogneisses support derivation from acid to intermediate magmas. These attributes are characteristic of the volcanic arc granite field (Pearce and Cann, 1973). The low contents of many of the elements, for example Rb, Nb, Pb, and Th in the orthogneisses compared to granitic averages may reflect losses during secondary processes. The Sr contents of the paragneisses ($177 \times 10^{-6} - 345 \times 10^{-6}$) indicate that K-feldspar was subordinate to Na-plagioclase in the sedimentary protoliths. The high contents of Zr in the paragneisses suggest that they were derived from highly metamorphosed sedimentary suites (McCurry, 1976; Ekwueme, 1998). The variability in values of this element in the orthogneisses and paragneisses can be attributed to the induced mobility as a result of high grade metamorphism and pervasive anatexis in the area leading to dispersal of the element.

Depletion in the incompatible elements and variability in trace element contents in the paraschists are probably due to metamorphic remobilization. However, the high contents of Cs indicate sedimentary origin, while the low contents of Sr and K/Rb ratios indicate a high level of crustal source. The wholesome mobility of usually immobile elements such as Y, Zr and P in the orthogneisses, paragneisses and paraschists indicates high-grade metamorphism of amphibolite to granulite facies.

The high Th contents of $84.0 \times 10^{-6} - 93.2 \times 10^{-6}$ suggest that the calc-alkaline granites are of crustal origin (Fourcade and Allegre, 1981; Onyeagocha, 1986). Trace element characteristics of the calc-alkaline granites strongly suggest that simple differentiation is the prime cause of their chemical variation. When plotted against various fractionation indices such as SiO_2, they show linear trends. Crystallization and fractionation trends in the calc-alkaline magmas show that mica is also an important liquidus phase in saturated magmas.

The K/Rb ratio decreases with fractionation and varies within the range of values normal for crustal derivation and typical of granitoids (Bertrand et al., 1984), whereas Rb and Rb/Sr ratio increase with fractionation. Trends of these types are known as the classical attributes of differentiating magma (Taylor, 1966). The geochemical similarities of the orthogneisses and granites depict their petrogenetic affinity, a relationship that is further supported by granites occurring at the peaks of the orthogneisses and migmatitic hills, suggesting anatectic alteration of the latter (Hyndman, 1972). Furthermore, the chemical pattern of the orthogneisses is partly inherited by the granites, as there is a regular pattern of enrichment from the orthogneisses to the granites, which further suggests that the granites were probably the products of orthogneisses.

The granites, which are K-rich, are characterized by enrichment of LILE. Such rocks have been interpreted to be derived either completely from enriched continental lithospheric mantle sources or, at least, contain melt fractions from such a source as mixing components (Peccerillo, 1992; Wenzel et al., 1997). Other special geochemical features of the granites suggesting crustal derivation include high contents of K-type (Ba, Sr), low K/Rb, and high Th/U ratios. The enrichment of their mantle sources is a product of post-collisional processes (Venturelli et al., 1984a, b; Wenzel et al., 1997). The high contents of heat-producing elements such as Th and K in the granites suggest that the heat production of the protoliths contributed significantly to the thermal evolution of the West African crust, similar to that in eastern Urals (Gerdes et al., 2002). Thus, the radiogenic heat production played an essential role in the generation of the continental-type granites of southern Obudu Plateau. The trace element compositions of the granites suggest a source from medium-pressure crystallization of LILE-enriched magmas.

Many trace elements such as Ba, Co, Cr, Ni, Rb, V and Zn are enhanced in biotite (Hall, 1988; Hetch, 1993), which is a very sensitive indicator of the physical and chemical conditions and compositional evolution in the genesis of granitoids (Speer, 1984; Siebel et al., 1977). The fact that biotite and muscovite were the crystallizing phases as reflected in the occurrence of 2-mica granites in the study area requires a certain amount of water. The differing Sr contents may be a reflection of the differences in the proportion of plagioclase in the residue during partial melting or fractional crystallization.

The close association of orthogneisses, paraschists, amphibolites and charnockites in southern Obudu Plateau suggests that the charnockites might have been hybrid, formed at low water pressure under anatectic conditions in the crust. This produced hypersthene and plagioclase from transformed hornblende and decomposed micas (Ukaegbu, 2003). The hybridization may have taken place at a thermal peak of granulite facies metamorphism, which followed crustal collision between the West African and Benin-Nigerian plates (Attoh, 1998; Affaton et al., 2000). Todt et al. (1995) suggested that such process took place before or close to the end of thermal peak of metamorphism.

The depletion of U and LILE in the charnockites is a primary feature of their source (Venturelli et al., 1984a, b). The variability in trace element concentrations indicates levels of crustal emplacement, while the low Sr, Y, Sc, V and high Rb, W, Th, U and K-type contents are interpreted to indicate some degree of contamination of the charnockites. It is, therefore, likely that the contamination of mantle-derived magma by anatectic products of the crustal host rocks of the amphibolite-granulite facies grade resulted in the crystallization of plagioclase and hypersthene responsible for the positive Eu anomaly in the charnockites. This is evident in the high modal plagioclase (24%) and hypersthene (27%) contents of the charnockites. The effect of K-feldspar is stronger and that of biotite fractionation, lower in the granites than in the charnockites on account of much higher Ba contents in charnockites than in granites. High Sr contents in the charnockites are probably due to low water activity during melting. The greater enhancement of Rb in granites than in charnockites may be due to fractional crystallization or partial melting or even alteration.

The higher trace element concentrations and K/Rb ratios of these dolerites than those of the Oban Massif indicate that they are higher-level (crustal) derivatives than the latter. The average trace element data support the origin by partial melting and separate magma phase of the dolerites from the early monzodiorites and granites, which they intruded. However, the low contents of Ni and absence of Cr in the dolerites are not consistent with the concentration levels of these elements in mafic igneous rocks. They suggest derivation from high-level magmatic source, probably the upper crust, which has been depleted in these elements, perhaps due to fractional crystallization. The dolerites also have higher levels of trace element concentrations and K/Rb ratios, except for Ni, Cr, Cu and Rb, than those of the adjacent Oban Massif (Ekwueme, 1990b), suggesting that these dolerites are derived from higher differentiation of basaltic magma in the upper crust than those of the Oban Massif.

A higher ratio of K/Rb in the dolerites than in the granites reflects Rb depletion in the source material. The wide gap between the ratios of K/Rb of the dolerites, on one hand, and those of the granites and charnockites, on the other hand, is probably an indication of separate source materials for both groups. The intrusion of dolerites into the highly evolved granitic series not only shows that they are younger than the latter, but also suggests that they are genetically-unrelated. Thus, while the granitic series may be the products of anatectic melting, the dolerites may be the products of fairly fast eruption from separate basaltic magma chamber, allowing little evolution as a result of very intense tectonic activity in the area. The trace element geochemistry of the igneous rocks as a whole indicates a polymagmatic origin. The low contents of Cr, Ni and Lu in the charnockites and dolerites may suggest that these rocks have suffered olivine + spinel fractionation at depth.

Overall, the geochemistry of the entire basement rocks of southern Obudu Plateau shows that K/Rb ratios in the orthogneisses, paragneisses and paraschists (189 - 259) are consistent with those of the upper crust (Fourcade and Allegre, 1981; Bertrand et al., 1984; Onyeagocha, 1986). Since the basement rocks of southern Obudu Plateau are composed mainly of orthogneisses, paragneisses and paraschists, the evolution of the basement rocks of southern Obudu Plateau is consistent with the ensialic crustal processes observed for the Nigerian Basement Complex (Ajibade and Fitches, 1988). Low K/Rb ratios in the orthogneisses, paragneisses, paraschists and granites are also consistent with the high modal values of biotite in these upper crustal rocks. The extremely high Sr contents in the charnockites indicate the abundance of plagioclase phases in these rocks, whereas the lower concentrations in the granites and orthogneisses are an indication of the subordinate nature of plagioclase to K-feldspar in the rocks.

Therefore, the ratios of different parameters, especially K/Rb, Rb/Sr and Th/U, show behaviours consistent with crustal to mantle derivation. The trace element contents suggest that the Plateau is a crystallization product of a combination of primary and residual melts. The dominantly intermediate nature of the source rocks of the orthogneisses is suggested by the generally high contents of Sr, low contents of Rb, Nb, Pb, Th and absence of Ni and Cr. Thus, the trace element contents in the Obudu Plateau are heterogeneous, reflecting mantle to crustal petrogenetic variations of the different rock suites in the Plateau.

5 Tectonic setting

Derived from different discrimination diagrams, the rocks of the Obudu Plateau were formed under diverse geologic events, which probably correspond to different sources of geodynamic disturbances. The orthogneisses plot within the VAG + syn-COLG field on the Nb-Y and Rb vs. (Y + Nb) discrimination diagrams of Pearce et al. (1984) (Figs. 2 and 3). On the Rb vs. (Y + Nb) discrimination diagram of Pearce (1996) (Fig. 4), the orthogneisses plot essentially within the VAG field and cluster nearer the post-COLG field than the syn-COLG field. The low Nb contents and high SiO_2 contents of the orthogneisses show they are actually of orogenic emplacement. This is evident on the Nb-SiO_2 binary diagram (Fig. 5). As viewed from all the geochemical features of the orthogneisses, they are comparable with the characteristics of granitoids at the orogenic continental margins (i. e., collision zones) (McCurry and Wright, 1977; Petro et al., 1979; Thorpe, 1979; Thorpe and Francis, 1979). The geodynamic evolution of the paraschists of southern Obudu Plateau is similar to that of the schist belt of Nigeria which is associated with a large ensialic terrain (Elueze, 1977; Olade and Elueze, 1979). Thus, the emplacement of these paraschists at a continental margin of the West Africa Craton due to collision between this craton and a westward moving plate resulted in the metamorphic sequence of paraschists characteristic of the event.

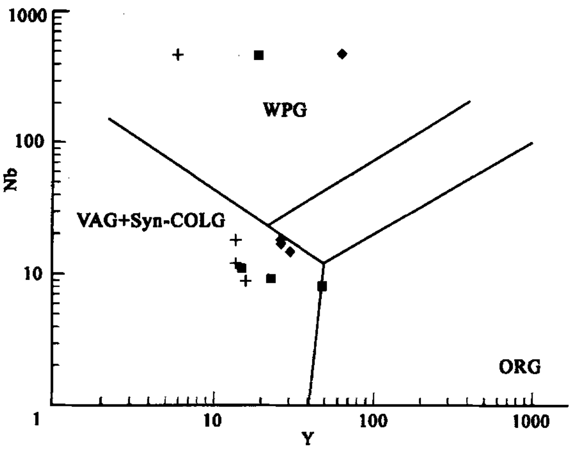

Fig. 2. Nb versus Y binary diagram of Pearce et al. (1984) showing the tectonic settings of the granites (+), charnockites (◆) and orthognasses (■) within the VAG + Syn-COLG fields.

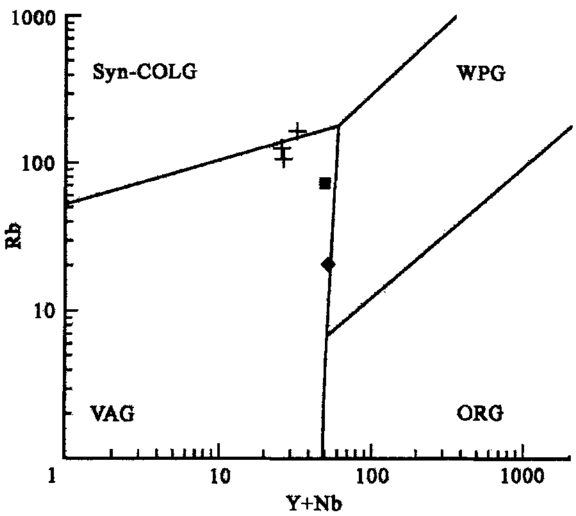

Fig. 3. Rb versus Y + Nb binary diagram of Pearce et al. (1984) showing the tectonic setting of the granitoids [granites (+), charnockites (◆) and orthogneisses (■)].

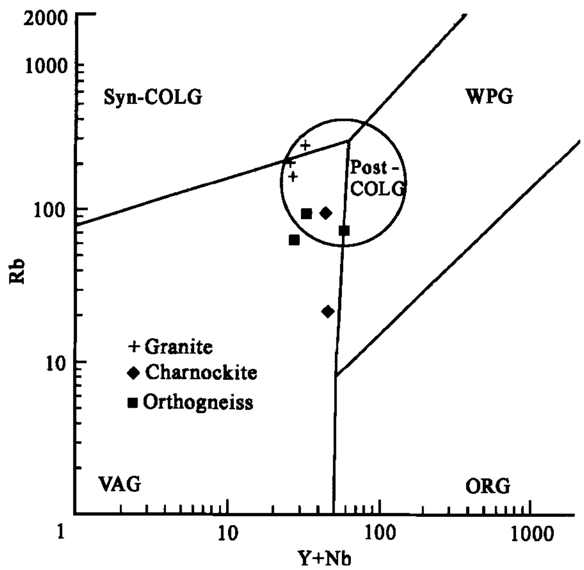

Fig. 4. Rb versus Y + Nb binary diagram of Pearce (1996) showing the tectonic setting of the granitoids.

The granites have similar geochemical affinities with the continental margin suites of the Tassendjacent and Gara Akafo zones of Algeria (Chikhaoui et al., 1980). The relative depletion in Sn-Nb-Ta association and enrichment in K further show that they are subduction-related. On the Nb-Y binary diagram (Fig. 2) the granites plot within the VAG + syn-COLG field. This is also consistent with the Rb vs. Y + Nb variation diagram (Fig. 4) which also shows that the granites are of post-collisional emplacement in an orogenic setting as indicated on the Nb-SiO_2 variation diagram (Fig. 5). The granites are consistent with the emplacement in a continental arc setting similar to that of the Andes. It is presumed that these granites were formed from crustal magmas generated after the metamorphic episode associated with orogenies related to the closure of the West Africa Sea located within an ancient convergent plate boundary.

The charnockites plot within the volcanic arc field. This is in agreement with the plot of the charnockites within the VAG + syn-COLG field on the Nb-Y variation diagram (Fig. 2) and the VAG field on the Rb vs. Y + Nb variation diagram (Fig. 4). It is also consistent with its plot within the orogenic field on the Nb-SiO_2 discrimination diagram (Fig. 5). The charnockites represent the distinct phases of new materials from depth and plot within the orogenic setting field. They are high-K andesites similar to those of the Andes formed from magmas near ancient convergent plate boundary. The existence of the charnockitic suites along side granite suites indicates two separate magmas that evolved along more or less parallel paths. These subduction-related charnockites have many geochemical features of partial melting of contaminated continental crust products, such as high K/Rb, low Rb/Sr, higher Ba and Sr, and lower Rb, W, Th and U, which clearly differentiate them from their spatially related continental-type 2-mica granites. On the Nb-

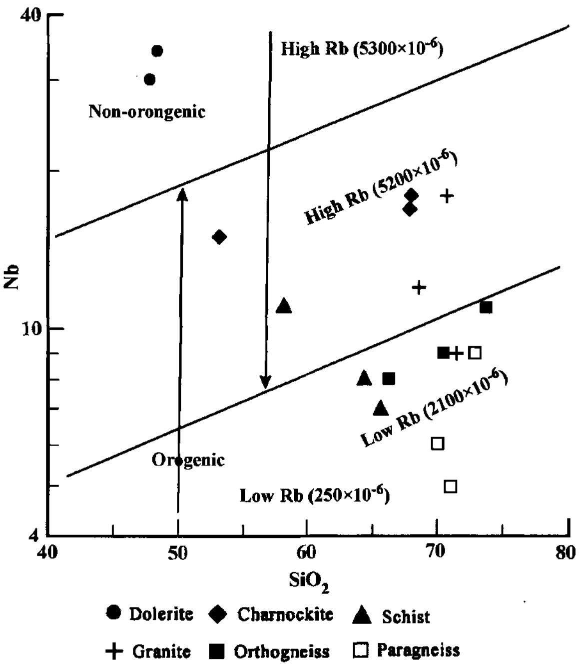

Fig. 5. Nb-SiO_2 binary plot for rocks of the Obudu Plateau showing occurrences from orogenic fields for charnockites and dolerites to non-orogenic fields for the orthogneisses, paragneisses and schists (from McCurry and Wright, 1977).

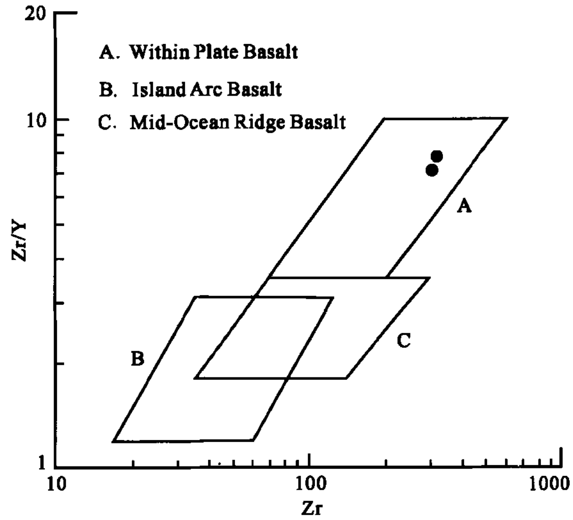

Fig. 6. Zr/Y versus Zr diagram illustrating the tectonic setting of the dolerites (after Pearce and Norry, 1979).

SiO_2 variation diagram (Fig. 5) the dolerites plot in a non-orogenic setting. This is supported by their undeformed and unmetamorphosed appearance in the field. The dolerites have also been dated to be of post Pan-African orogeny (Ekwueme, 1990b). On the Zr/Y vs. Zr variation diagram (Fig. 6) the dolerites plot within the WPB field, indicating that these rocks are products of rifts. The plot of the dolerites within the continental field confirms that the protoliths were continental tholeiites with basaltic derivatives, probably indicating the events of the separation of South America from Africa (Ekwueme, 1994).

Geodynamic disturbances in the mantle are responsible for the tectonic activities, which affected crustal development in the Pan-African basement domain of the Obudu Plateau. The rift system may have been set off by the response effect due to crustal decoupling swing along a suture at the eastern margin of the West African Craton, in various geologic periods. The fracture pathway may have been so penetrative that vast magma intrusions were resultant and were emplaced through all available fractures with little or no time to differentiate or evolve. The occurrence of dolerites, gabbros, amphibolites, cataclasites, mylonites and peridotites in southern Obudu Plateau supports this view. A model of the geodynamic development of the Obudu Plateau is shown in Fig. 7. The tholeiitic and calc-alkaline nature of magmatism and the occurrence of greywacke-pelite sequence are suggestive of an Andean-type continental environment (Jakes and White, 1972).

6 Conclusions

Trace element characteristics of the basement rocks of southern Obudu Plateau indicate that the Plateau has multiple protoliths and tectonic settings. The igneous rocks are of polymagmatic origin emplaced in diverse tectonic settings across volcanic arc granites and within plate basalts. They range from juvenile to highly fractionated rock suites. The granites were formed by crystallization from partial melts at medium pressure and dolerites are considered to be of crustal derivation, while the charnockitic rocks are of mantle origin. The metamorphism of the pelites, greywackes, basaltic rocks and granites reached the upper amphibolite to granulite facies grades. The orthogneisses are of volcanic arc setting, whereas the paragneisses and paraschists are of greywacke-pelite origin, emplaced in the collision zone. The rocks of the Obudu Plateau are heterogeneous, reflecting mantle to crustal petrogenetic variations. The Plateau has experienced cycles of seafloor spreading, sedimentation, subduction, collision and deformation, metamorphism, partial melting, migmatization and magmatism. The Pan-African post-subduction collision activities of the westward drifting eastern Sahara active continental margin shield under the passive continental margin of the West African Craton resulted in intense and pervasive reactivation of the basement units of the Plateau.

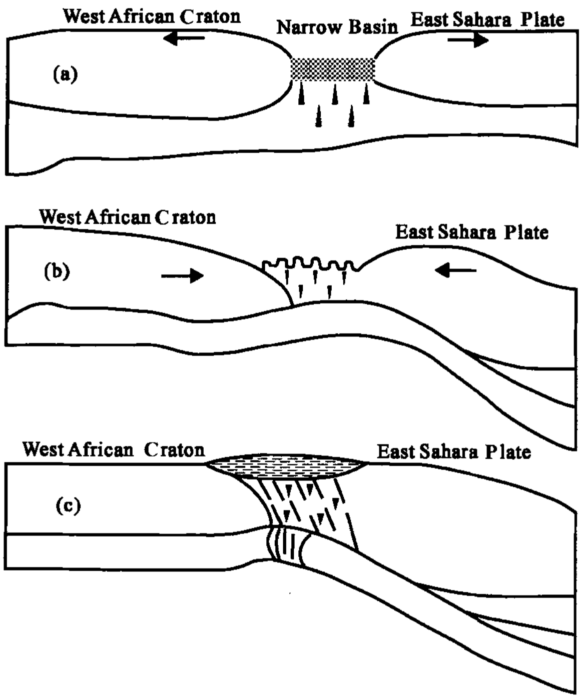

Fig. 7. Geodynamic model of southern Obudu Plateau. (a) Pre-subduction stage: Initial development of shallow sea between the West African Craton and East Sahara Craton probably as a result of rifting caused by continental drifting; eruption of basaltic magma into the shallow basin, and sedimentation of greywacke-pelite sequence and some quartz arenites into the shallow sea. (b) Subduction and collision stage: Widespread continental orogenesis and thickening during this period of collision between the two cratons. West African seaclosed with earlier basaltic and sedimentary materials deformed. (c) Late to post-collision calc-alkaline stage: This is the period of stabilized continental lithosphere; metamorphism of the earlier deformed igneous and sedimentary materials up to upper amphibolite to granulite facies grade; sequential magmatism from multiple sources; the rocks were weakly deformed; rifting and emplacement of lithospheric gabbros and dolcrites terminated the orogenic phase.

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