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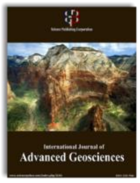

Trace element geochemistry and geotectonic settings of the charnockitic and associated rocks around ikare, southwestern Nigeria

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Abstract

The trace element concentrations of charnockites and associated rocks around Ikare were investigated in this study. Previous works on the genesis and tectonic settings of these rocks around Ikare were inconclusive due to lack of trace element data. Hence, this study was designed to determine the trace element compositions and use them to interpret their tectonic setting. Forty (40) representative rock samples were subjected to geochemical analyses using inductively coupled- plasma mass spectrometer. Results showed that most rocks are enriched in Ba, Sr, Zr but depleted in Rb suggesting their improverishment in the source rock. K/Rb ratios ranged from 153ppm to 374ppm for all rocks, while Ba/Sr ratios are high indicating that they are not mantle derived but through internal differentiation of pre-existing TTGs intra-crustal melting. On the Sr/Y discrimination diagram, the rocks plot in the post-Archean field. On the Y versus Nb and Rb versus Y+Nb, the rocks indicated magmatic origin in pre-to syn-collisional orogenic tectonic setting.

Keywords: *Archean; Charnockites; Geochemical; Ikare; Intra-Crustal Melting.*

1. Introduction

Rock suites outcropping around Ikare are parts of the southwestern Basement Complex of Nigeria. This complex lies within the proterozoic mobile belt extending from beyond Hoggar to the Congo shield. This mobile belt is sandwitched between the West Africa Craton in the west and the Congo Craton to the east. Rahaman [1], Olaide et al. [2], Ekwueme et al. [3], Ajibade [4], and Ekwueme [5] opined that this belt had been subjected to thermo-tectonic events. This area consists of high grade metamorphic rocks (transition zone from amphibolite to granulite facies) such as migmatites, grey and granitic gneisses, quartzite, pelitic gneiss, charnockitic gneisses, patchy charnockite, intrusive charnockite and granite (Fig.1). Charnockitic and granitic rocks intruded into the host gneisses (grey and granite gneiss). Ekwueme [5], Ekwueme [6], Ukaegbu et al. [7] observed that the rocks generally trends NW and dip westwards as in the case of the southeastern Obudu Plateau. Trace elements appear in very low concentrations in widespread rocks frequently < 0.1% by weight. Unlike major elements, trace elements are likely to be incorporated into fewer minerals, therefore they provides valuable information for magmatic differentiation and in number of cases forecast the source of a specific magma (Tyler, [8]). There is scanty data on the trace element geochemistry of charnockitic and associated rocks around Ikare and this paper intends to produce the trace element data and interpret them with a view of determining the tectonic evolution of rocks around Ikare, southwestern Nigeria.

2. Local geological setting

Detailed geological mapping of the study area revealed the following lithologies: The gneisses (grey. granite, biotite and charnockitic), charnockite, granite and pockets of quartzite. Granite gneisses are the predominant rock types and serves as host to other rock types (Fig.1). In terms of the mineralogical composition, the rocks contain quartz, plagioclase feldspar, alkali- feldspar, biotite and hornblende for the granite and gneisses. In addition, the charnockitic rocks contain orthopyroxene ± clinopyroxene. Accessory minerals are ilmenite, apatite, magnetite, chalcopyrite and titano-magnetite. Myrmekite intergrowth and perthitic feldspars are common in most rock types sampled in the study area. Charnockitic occur in three forms namely (i) as mappable intrusive charnockite, (ii) as charnockite patches in host gneiss and (iii) gneissic charnockite. These charnockitic bodies are found as enclaves within the host gneisses. The field relation between these rocks is gradational or transitional. The general strike direction is notably NW with few outcrops striking NE (Fig. 1). Also, most of the outcrops dip towards SW, with few exceptions.

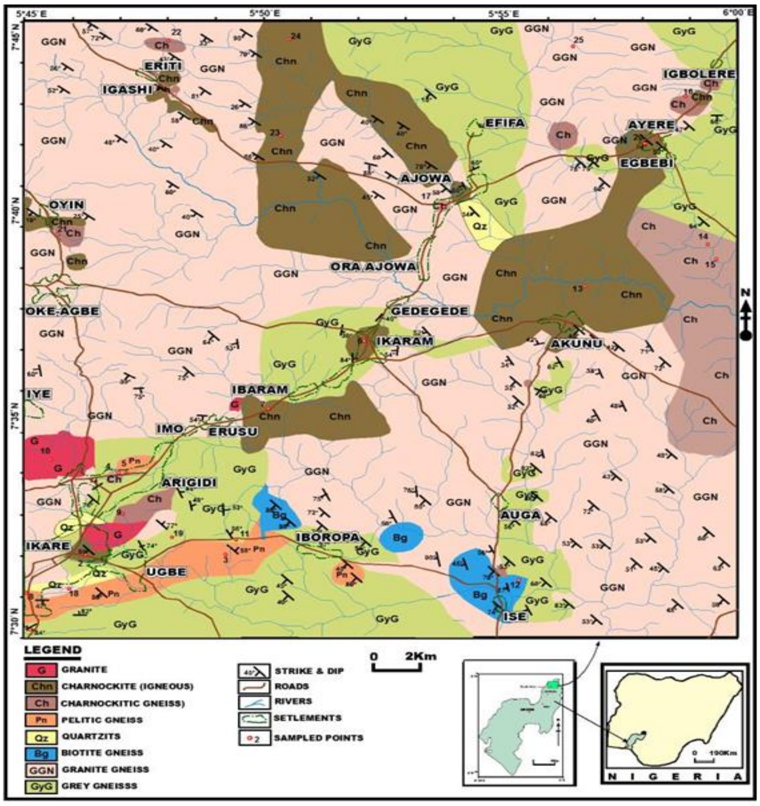

Fig. 1: Geological Map of the Study Area Showing the Main Lithological Units.

3. Materials and methods

Forty (40) representative samples of the charnockitic and associated rocks of the study area were subjected to trace element analyses using inductively coupled plasma- mass spectrometer (ICP-MS) housed at the University of Potsdam, Potsdam, Germany. Rock samples were crushed and powdered in an agate mill to a size of grain (below 63µ) appropriate for analyses. The samples were later dried at 105^{0}C. 3.0g of Na_2O_2 and I.0g of powdered and dried samples are weighed in a platinum or nickel crucible. The crucibles were positioned in a muffle kiln and kept at 480^{0}C± 10^{0}C for 1 hour. Trace element studies of the rocks such as elements from d-block, alkali and alkali-earth elements such as Rb, Sr and Ba and lanthanide group of elements are used to infer petrogenetic information. Results are shown in Tables 1 – 5.. These results are compared with similar occurrences in different parts of the world.

4. Results and discussion

4.1. Result

4.1.1. Trace elemental composition

There is enrichment of Ba, Sr, Zr and depletion in Rb contents in these rocks (Tables 1- 5). Barium and strontium are particularly enriched in the charnockites and other rocks studied. This enrichment may be attributable to replacement of Sr for Ca in the plagioclase and Ba for K-feldspars (Blundy et al. [9]; Mahood et al. [10]). In the intrusive charnockite, Ba contents ranged from 495 to 1545ppm (Table 1). For the charnockitic gneiss, Ba ranged from 448 to 985ppm while those of patchy charnockite ranged from 620 to 986ppm (Tables 2 and 3). The Barium contents in the gneisses (grey and granite gneiss) ranged from 549 to 1337ppm, while in the granite, it ranged from 729 to 1123 (Tables 4 and 5). For strontium, it ranged from 108 to 206ppm in the intrusive charnockite and 253 to 567ppm in the charnockitic gneiss (Tables 1 and 2). Again, for the gneisses, it ranged from 129 to 435ppm. Sr contents in the charnockites and associated rocks of Ikare are higher in values than the values for potassic porphyritic granites from some parts of southwestern Nigeria (Rahaman et al. [1]) and average for granites (Tyler [8]). The high contents of Ba and Sr in these rocks resembles the high Ba-Sr granitoids found in different parts of the world (Rajesh et al.[11]). Rb contents are generally low in these rocks. For the charnockites, it ranged from 64 to 141ppm in intrusive charnockite and 50 to 141ppm in charnockitic gneiss (Tables 1 and 2). Similar ranges were obtained for the gneisses where it ranged from 121ppm to 227ppm (Table 4). In the granites, Rb contents recorded the lowest values of 55-76 ppm (Table 4).

Table 1: Trace Element Data (Ppm) for the Charnockite from Ikare Area

Sample No	Ni.9a	Ni.14	Ni.15	Ni.17	Ni.4	Ni.21	Ni.22	Ni.9b	N,15b	Ni. 17b	Av.	Range	
Trace elements (ppm)	100.07												
Ba	1007	1549	495	1023	1375	1450	1540	1530	1370	1451	1155.2	495	1549
Cr	63	94	233	49	80	75	83	230	90	80	107.7	49	233
Ga	18	17	17	20	20	17	18	17	20	17	18.1	17	20
Nb	23	20	11	26	14	22	20	25	18	20	19.9	14	26
Ni	24	40	87	13	28	38	42	40	35	45	39.2	13	87
Rb	64	81	101	141	50	80	102	65	110	115	95.4	50	141
Sr	197	201	201	108	153	206	201	190	202	198	185.7	108	206

V	52	53	112	30	189	55	57	53	55	55	71.1	30	189
Y	49	37	47	64	55	23	37	48	47	48	45.5	23	64
Zn	84	113	83	78	158	86	112	110	85	80	99	78	158
Zr	763	600	306	576	276	630	580	650	615	570	556.6	276	763
K_2O/Na_2O	0.88	1.16	0.81	1.36	0.29	0.82	1.36	0.75	0.85	0.76	0.90	0.29	1.36
K/Rb	336	326	190.6	252.5	ND	335	325	320	335	326	274.6	190.6	336
Ba/Rb	15.7	19.1	4.9	7.25	13.7	18.1	15.1	12.7	12.4	12.6	13.15	4.9	19.1
Ba/Sr	5.11	7.7	2.46	9.47	0.89	7.03	7.66	8.05	6.53	7.32	6.22	0.89	9.47
Sr/Y	4.02	5.43	4.27	1.68	2.78	8.95	5.43	3.95	4.29	4.12	4.49	1.68	8.95
Rb/Sr	0.32	0.4	0.5	1.3	ND	0.38	0.5	0.34	0.54	0.58	0.54	0.32	1.30
ASI	1	1	0.7	1	1.4	1	1	1	1	1	1.01	0.70	1.40

Av: Average

Table 2: Trace Element Data (Ppm) for the Patchy Charnockite and Charnockitic Gneiss from Ikare Area

Trace Element (ppm)	Ni 2a	Ni.2b	Ni 2c	Ni 6	Ni.7	Ni.13	Ni.19	Ni.20	Ni.23	Ni.24		
Ba	986	689	620	448	464	607	656	466	465	645	604.6	986
Cr	43	55	73	99	72	86	61	179	64	84	81.6	179
Ga	17	19	21	16	22	18	17	18	17	16	18.1	22
Nb	<10	13	15	<10	< 10	11	11	< 10	11	< 10	12.2	15
Ni	14	15	22	42	43	42	19	44	42	20	30.2	44
Rb	141	133	95	50	69	113	97	78	68	98	94.2	141
Sr	311	297	290	394	567	253	297	349	394	348	350	567
V	48	68	97	93	108	93	65	142	107	68	88.9	142
Y	11	35	55	<10	20	18	35	23	18	< 10	24.3	55
Zn	47	70	75	72	83	58	62	97	57	70	69.1	97
Zr	162	246	327	135	180	186	250	134	184	180	198.4	327
K_2O/Na_2O	1.59	1.2	0.9	0.43	0.53	1.25	1	0.48	0.5	1	0.88	1.59
K/Rb	256	220	239	227.4	233.4	254	229.3	154.3	228.2	229.2	227.0	256
Ba/Rb	6.99	5.18	6.52	8.96	6.72	5.37	6.76	5.97	6.83	6.17	6.54	8.96
Ba/Sr	3.17	2.32	2.13	1.13	0.81	2.4	2.2	1.33	1.18	1.73	1.84	3.17
Sr/Y	28.2	8.48	5.27	ND	28.3	14	8.48	15.1	21.8	ND	16.2	28.3
Rb/Sr	0.45	0.44	0.32	0.12	0.12	0.44	0.32	0.22	0.17	0.28	0.28	0.45
ASI	1.0	1.0	1.0	1.0	0.9	1.0	1.0	1.0	1.0	1.0	1	1

Sample No: Ni.2a, Ni.2b, Ni.2c – Patchy charnockite
Ni 6, Ni.7, Ni.13, Ni.19, Ni.20, Ni.23 – Charnockitic gneiss

Table 3: Trace Element Data for the Grey and Granite Gneisses from Ikare Area

Trace elements (ppm)	Ni.1a	Ni.1c	N.11	Ni.1d	Ni.1b	N.18	Ni.25a	Ni.25b	Av	Range	
Ba	1228	1074	742	670	1337	549	780	550	866.3	549	1337
Cr	49	48	55	48	32	49	48	47	47	32	55
Ga	18	20	16	17	16	18	18	18	17.6	16	20
Nb	10	10	10	10	10	<10	10	10	10	10	10
Ni	14	13	20	15	13	15	15	15	15	13	15
Rb	152	121	121	122	171	227	174	178	158.3	121	227
Sr	408	435	354	430	276	129	276	128	304.5	128	435
V	45	42	87	42	16	28	16	18	36.8	16	87
Y	25	24	35	30	17	15	17	15	22.3	15	35
Zn	46	49	70	47	30	48	30	45	45.6	30	70
Zr	287	257	251	250	212	137	136	138	208.5	136	287
K_2O/Na_2O	1.25	0.88	1.08	1.00	1.67	1.57	1.88	1.67	1.37	0.88	1.88
K/Rb	221	221	219	220	203	153	153.6	153.5	193.0	153	221
Ba/Rb	8.07	8.87	6.13	5.49	7.81	2.41	4.48	3.64	5.86	2.41	8.87
Ba/Sr	3.01	2.46	2.09	1.55	4.84	4.25	6.1	4.29	3.57	1.55	6.10
Sr/Y	16.32	10.35	10.11	14.33	16.23	8.6	16.23	18.26	13.8	8.60	18.26
Rb/Sr	0.37	0.27	0.34	0.28	0.62	1.76	0.63	0.65	0.61	0.27	1.76
ASI	1	1	1	1	1	1.1	1	1	1	1	1

Sample No: Ni 1a, Ni.1c, Ni.11, Ni. 1d – grey gneiss
Ni.1b, Ni.18, Ni.25a, Ni.25b – granite gneiss
Av- Average

Table 4: Trace Element Data (Ppm) of the Granite from Ikare Area

Trace Element (ppm)	Ni.10a	Ni.10b	Ni.10c	Ni. 16a	Ni.16b	Average	Range	
							Low	High
Ba	729	1123	750	1120	728	890	729	1123
Cr	53	37	48	50	52	48	37	53
Ga	18	25	18	20	25	21.2	18	25
Nb	,< 10	29	28	< 10	30	29	< 10	30
Ni	21	13	15	20	13	16.4	13	21
Rb	58	76	60	55	58	61.4	55	76
Sr	311	345	313	315	315	319	311	345
V	58	38	47	59	58	52	38	59
Y	12	44	20	15	40	26.2	12	44
Zn	42	75	43	43	42	49	42	75
Zr	254	550	540	256	256	371	254	550
K_2O/Na_2O	0.44	0.88	0.74	0.38	0.48	0.58	0.38	0.88
K/Rb	204.6	374.6	205.5	204.3	204.5	238.7	204.3	374.6
Ba/Rb	13.6	14.77	12.5	20.3	12.5	14.7	12.5	14.77

Ba/Sr	2.34	3.25	2.39	3.55	2.31	2.76	2.31	3.55
Sr/Y	25.91	7.84	15.65	21.0	7.87	15.65	7.84	25.91
Rb/Sr	0.18	0.22	0.19	0.17	0.18	0.18	0.17	0.22
ASI	1	1	1	1	1	1	1	1

Table 5: Trace Element Data (Ppm) of the Pelitic Gneiss from Ikare Area

Trace Elements (ppm)	Ni.3a	Ni.3b	Ni.3c	Ni.5	Ni.8a	Ni.8b	Ni.8c	Average	Range	
									Low	High
Ba	429	395	392	511	390	450	398	423	390	511
Cr	235	165	293	163	160	280	167	209	160	293
Ga	23	24	30	26	25	28	30	26.5	23	30
Nb	23	24	19	22	22	26	20	22.2	19	26
Ni	87	55	82	54	56	70	55	65.5	54	87
Rb	148	112	93	110	112	92	116	111.8	92	148
Sr	153	65	230	62	68	150	220	135.4	62	230
V	211	175	167	177	210	170	165	182.1	165	211
Y	47	25	< 10	26	48	30	46	37	< 10	48
Zn	131	110	147	104	105	112	140	121.2	104	147
Zr	183	403	257	322	182	251	320	274	182	403
K_2O/Na_2O	1.53	2.72	0.74	2.97	2.35	1.14	0.90	1.76	0.74	2.97
K/Rb	149	137	185	148	145	150	148	151.7	137	185
Ba/Rb	2.89	3.52	4.21	4.64	3.48	4.89	3.43	3.86	2.89	4.89
Ba/Sr	2.80	6.07	1.70	8.24	5.73	3.00	1.81	4.19	1.70	8.24
Sr/Y	3.25	2.60	ND	2.38	1.41	5.00	4.78	3.23	1.41	4.78
Rb/Sr	0.96	1.72	0.40	1.77	1.64	0.61	0.52	1.08	0.40	1.77
ASI	1.5	2.9	1.6	3.0	2.5	2.0	2.5	2.2	1.5	3.0

ND – Not Determined

Table 6: Trace Element Data (Ppm) of Some Rocks from Obudu Plateau, SE Nigeria (After Ukaegbu, 2003)

Trace Elements	Ba	Rb	Sr	Y	Zr	Nb	Ga	Zn	Ni	Cr
1.	411	106	248	10	131	77	21	11	-20	-0.3
2.	20	22	978	30	574	15	20	20	-20	-20

1) Average trace element compositions in orthogneiss from southeastern Obudu (Ukaegbu,2003)
2) Average trace element compositions in intermediate charnockite (enderbite) from Obudu (Ukaegbu, 2003)

4. 2. Discussion

The extreme enrichment in Ba and Sr in these rocks had been attributed to high-localized mobility (Ukaegbu [12]). The charnockitic and gnessic rocks of the study area are more enriched in these elements when compared with the gneisses of Kabba-Lokoja are (Odigi et al. [13]) and granitic rocks from southeastern Obudu (Ukaegbu [12]) with lower strontium contents (Table 5). The K/Rb ratios of intrusive charnockite ranged from 190 to 336ppm, while those of the charnockitic gneiss ranged from 154ppm to 223ppm. In the patchy charnockite, it varied from 220ppm to 256ppm and for the gneisses it varied from 153ppm to 221ppm (Table 2). These high K/Rb ratios obtained for the charnockites and associated rocks of Ikare are similar to those of archetypal TTGs that are common in Archean rocks occurring globally (Jahn et al. [14] and Sheraton et al. [15]). K/Rb ratios of 153 – 374ppm for all rock types in the study area are higher than the crustal average range of 150 to 300ppm (Taylor [16]) or the K/Rb range for low- and high- calcium granites of 229 – 247ppm (Turekian et al.[17]), which suggest (i) relative improverishment in Rb or (ii) relative enrichment in potassium. However, (Rollision et al.[18]) opined that these rocks derived their Rb depletion from their igneous protolith and predates metamorphism. The Ba/Rb ratios of intrusive charnockite ranged between 4.90 and 19.1 (av =13.15), while those of charnockitic gneiss and patchy charnockite ranged between 5.18 and 8.96 (average =6.54). For the gneisses, Ba/Rb ratios ranged from 2.41 to 8.87 (Table 2). Generally, Ba/Rb ratios are high for these rocks, except for the metapelitic rocks, suggesting that they are not mantle derived but from internal differentiation of a pre-existing crust of trondhjemite-tonalite-granodiorite –type during intra-crustal melting (Hofmann [19]) (Table 5). Ba/Sr ratios ranged between 0.81 and 9.47 for all rock types and fall within average values for low- and high- calcium granites. The Rb/Sr ratios are low for both charnockitic rocks and associated gneisses. Charnockitic rocks have average values between 0.28 and 0.54 for Rb/Sr ratios, while the gneisses varied from 0.27 to 1.76 (Tables 2 & 3).

4.2.1 Petrogenesis and tectonic setting

The Rb/Sr ratios obtained for the rocks are greater than that of normal crustal rocks (0.24), for standard granites (0.9) (Mason [20]). Granitoids have been observed to be associated with diverse orogenic events based on discrimination diagrams (Harris et al [21]; Pearce et al.[22] and Bowden et al.[23]). On the Sr/Y versus Y diagram of (Defant et al. [24] and Castillo et al. [25]) revealed that majority of the Ikare rocks plot in post Archean granitic and island arc fields (Fig.2). Also from the plot of Nb versus Y of (Pearce et al. [22]), majority of the rocks are confined to volcanic arc granite, syn-collision granite (VAG + SynCOLG) fields, while few plot in the within plate granite (WPG) (Fig.3). The minimal levels of Nb concentrations relative to SiO_2 content of these rocks have led credence to this tectonic setting. Arc affinity is further indicated by minimal levels of Nb, Ta and Ti (Romer et al. [26] and Köksal et al. [27]). Also, on the diagram of Rb versus Y+Nb (Pearce et al. [22]), most samples plots in the volcanic arc granite (VAG) field with few in the within plate granite (WPG) (Fig.4). This scenario is similar to the works of (Abdul-salam [28] and Adeleye [29]) on the amphibolites of Itase and Wonu-Apomu areas of southwestern Nigeria. This make-up is widespread in the Archean granitoids (Windley [30]). The negative Rb and positive Sr anomalies for the studied rocks are compatible with the island arc nature of the magma (Thompson et al. [31] and Gill [32]). The comparative function of partial melting and fractional crystallization can be confirmed through aid of V versus Rb and Ni versus Ba diagrams (Cocherie [33] and de- Souza [34]), where sub-horizon models are ascribed for differentiated magma through production of partial melting, whilst fractional crystallization produces sub-vertical trend. From these diagrams, though considerable scattering can be observed on V versus Rb diagram, while on Ni versus Ba, the samples followed partial melting trend (Figs 5a and 5b). This is suggesting supremacy of partial melting over fractional crystallization in their petrogenesis. The rocks in the study area showed geochemical features of convergent plate boundary analoguos to the setting of Andean type and probably products of crustal magmas produced during or/ and after the thermotectonic events that affected the West African fold belt (Ukaegbu [12]). This is further confirmed by the discrimination R1 versus R2 (Batchelor and Bowden [35]), which showed that the samples plot in the pre-plate collision through syn-collision to post collision tectonic settings (Fig 6). The rocks showed similarity in their tectonic settings. The magma that produced the charnockites and granites were probably same, but were emplaced at different phases into already metamorphosed crust of gneisses and/or metamorphosed sediments in case of the pelitic gneisses.

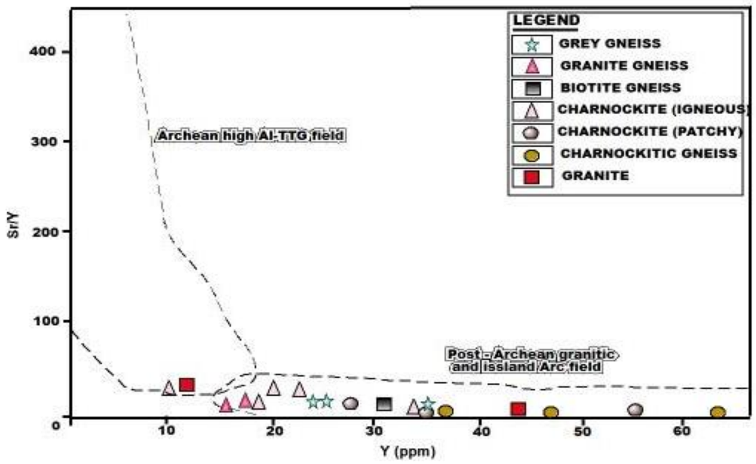

Fig. 2: Sr/Y Versus Y Diagram (After Defant and Drummond, 1990 and Castillo Et Al., 1999) for the Rocks in Ikare Area.

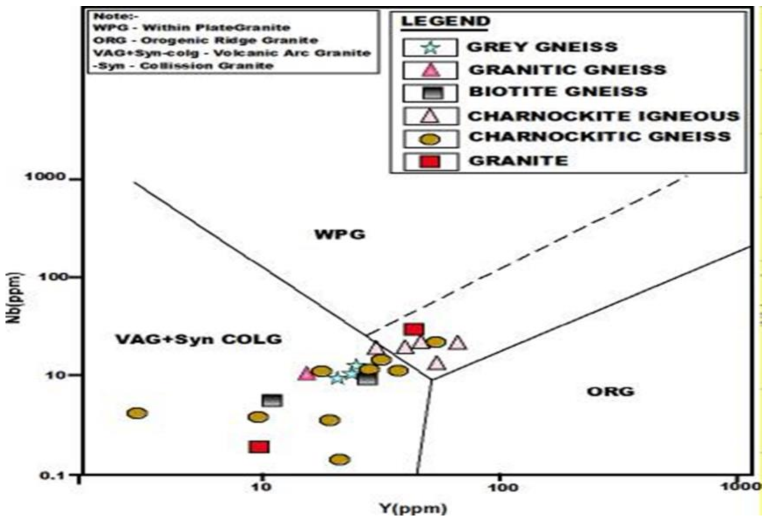

Fig 3: Nb Versus Y Showing Samples Plot in VAG + Syncolg and WPG Fields (After Pearce Et Al., 1984)

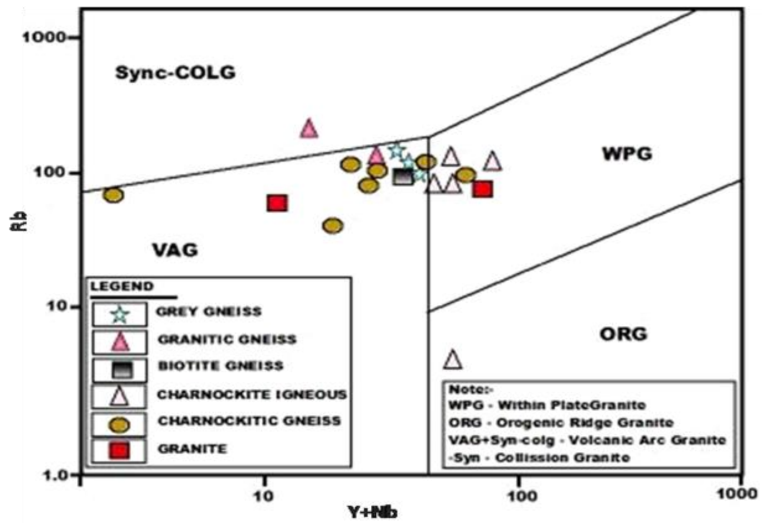

Fig. 4: Rb Versus Y+Nb Diagram of Discrimination for Ikare Rocks (After Pearce Et Al., 1984). Samples Plot in the Fields of Volcanic Arc Granites (Syn-Colg), within Plates Granites (Wpg) and Ocean Ridge Granites (Org).

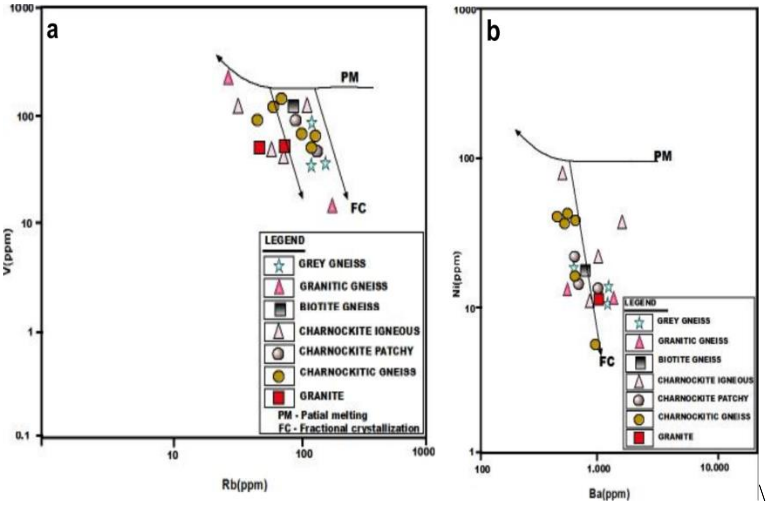

Fig. 5: (A) V Versus Rb Showing Clusterring of Samples Along Partial Melting and (B) Ni Versus Showing Scattering of Samples Along Fractional Crystallisation Trend (After Cocherie, 1986; De Souza Et Al., 2007)

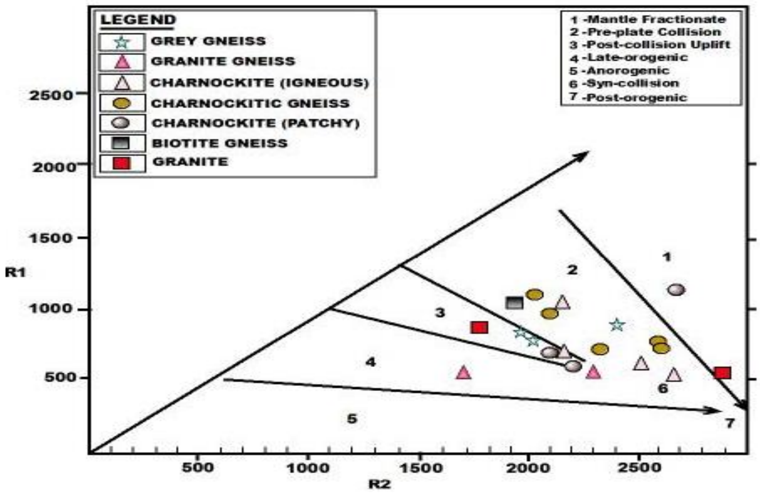

Fig. 6: R1 Vs R2 Tectonic Diagram Showing Samples Plot in Pre-Plate Through Syn- Collision to Post Collision Fields (Drawn After Batchelor and Bowden,1985).

5. Conclusion

The basement rocks outcropping around Ikare, southwestern Nigeria have varied tectonic settings and several but similar protoliths. The trace element concentration have indicated partial melting of the lower crustal materials followed by magmatic differentiation. High Sr contents can be linked to contamination during ascent. These siliceous rocks were emplaced in diverse tectonic settings that ranged from volcanic arc to collisional orogenic events.

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