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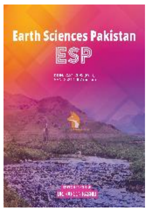

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RESEARCH ARTICLE

RARE EARTH GEOCHEMISTRY AND PETROGENESIS OF CHARNOCKITIC AND ASSOCIATED ROCKS AROUND IKARE, SOUTHWESTERN NIGERIA

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ABSTRACT

Charnockitic and associated rocks outcropping around Ikare were investigated for their rare earth element concentration and distribution patterns. REE data on these rocks are scanty due to lack of geochemical data. Hence, this study was designed to determine the rare earth element distribution patterns and infer the nature of their protoliths. A total of 40 rock samples were subjected to geochemical analyses using inductively coupled plasma-mass spectrometry. Results showed that igneous charnockites are more enrinched in average total REE of 278.75, while the granite had the least of 151.52. All the rock samples showed a strong compositional similarity with pronounced enrichment in light rare earth elements in relative to heavy rare earth elements. La/Yb_N ratios for all rock types are above 5 with the metapelites having average ratio of 40.6. The Gd/Yb_N ratios are below 2.0 for the charnockitic rocks. The rocks generally showed significant europium anomalies due to previous segregation of Ca-rich phases such as Ca-rich plagioclase for a magmatic origin or Ca-poor protolith in case of metasedimentary. Eu/Eu^*anomalies are below 1.0 for charnockitic and gneissic rocks except for the granites. It is evident that the precursors of these rocks evolved through magmatic differentiation processes and signaled partial melting of the lower crust which was later got contaminated at the upper crustal level.

KEYWORDS

protoliths, europium, magmatic differentiation, partial melting, Ikare

1. INTRODUCTION

Rare earth elements are separated into heavy rare elements and light rare elements dependent on their atomic mass and radius (Tyler, 2004). The light rare elements consist of La, Ce, Pr, Eu, Nd, Pm and Sm, while the heavy rare earth elements consist of Er, Gd, Ho, Th, Tm, Dy, Yb and Lu. The rare earth elements concentrations in chondrite are used for the normalization and presentation of geochemical data. Over the years, REE (rare earth elements) have been deployed in the determination of petrogenesis of granitic rocks, most especially in granites (de Albuquerque, 1978; Hanson, 1980; Sial et al., 1981). The study area, Ikare and its environs is located in southwestern Nigeria and lies between latitudes 7⁰ 25ⁱ - 7⁰ 45ⁱ N and longitudes 5⁰ 40ⁱ – 5⁰ 60ⁱ E (Figure 1). Notable towns and villages are Ikare, Iboropa, Arigidi, Erusu, Auga, Akunnu, Ajowa, Ikeram-Ibaram, Igashi and Oke-Agbe.

The area is differentiated by relatively rocky undulating hills and mountains comprised of outcrops of Intrusive charnockite, gneisses (grey, granite, charnockitic, biotite,pelitic) and granites. These highlands ranged between 200 and 350 metres above the sea level. The outcrops of batholiths is scattered in the southern parts of the area close to Ikare and Oke-Agbe to the north. To the east, the area is characterized by lowland outcrops with gneissic ridges. The lowland terrains consist of pediplains and dissected complex plains while hills and batholith consists of undifferentiated metamorphic and igneous rocks. The highlands form the major watershed in the area.

The mapped rock units are charnockites (patchy, intrusive, gneissic), gneisses (grey, granite, biotite and pelitic) and granites. The predominant rock type is the granite gneiss with few outcrops of biotite and pelitic gneisses. The general strike direction is NW and dip in the SW (Figure 2). Detailed geological mapping and geochemical studies on rocks around Ikare had been inadequate. Moreover, few rare earth element data exists in literature. Olarewaju had provided some REE data for charnockites and associated rocks of Ikerre – Ado Ekiti axis, adjacent to Ikare, southwestern Nigeria (Olarewaju, 1998). This paper intends to use REE data and distribution patterns of the charnockites and associated gneissic rocks outcropping around Ikare, southwestern Nigeria to determine the nature of their protoliths.

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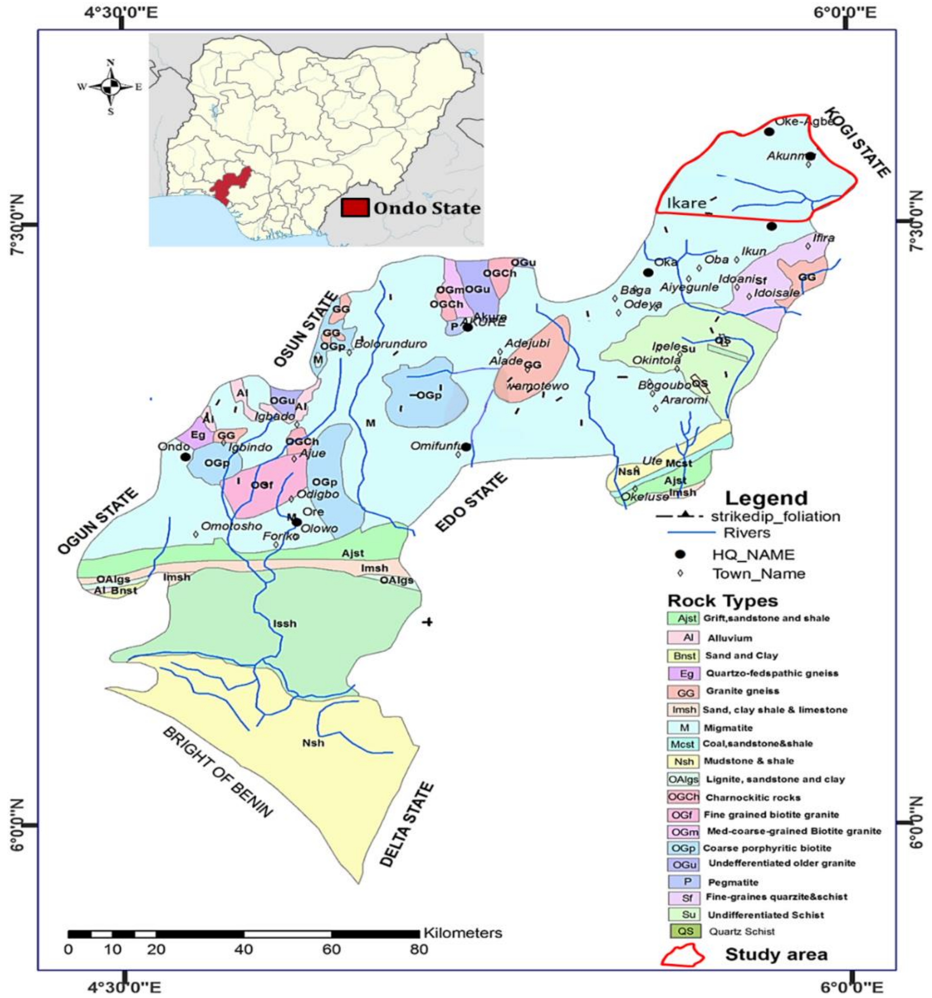

Figure 1: Simplified geological map of Ondo State, showing the location of study area.

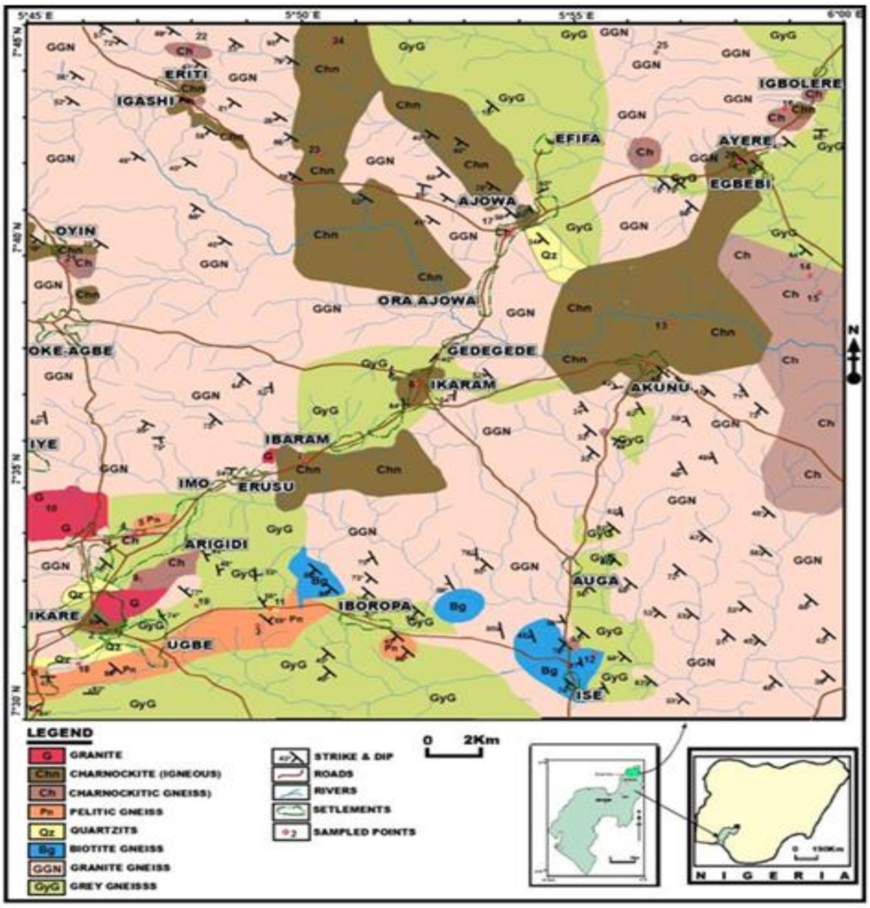

Figure 2: Geological map of study area, Ikare and environs.

2. MATERIALS AND METHODS

Geological mapping was carried out on a scale of 1: 50,000 using topographical map marked Ikole S.E sheet No. 245 published by then, Geological Survey of Nigeria (now, Nigerian Geological Survey Agency) as a base map. Traverses using were made through numerous road networks, footpaths and along streams. Locations and coordinates of rock exposures were recorded with the aid of Global Positioning System (GPS). Field relations and features were properly recorded on field notebook. Fresh representative samples of the rocks were collected for REE determination. Forty (40) REE have been examined on the charnockites and associated rocks, using Inductively Coupled Plasma Mass Spectrometry (ICP-MS) at the Universität Potsdam, Golm-Potsdam, Germany. Table 1 shows the locations, GPS readings and the mineralogy of the sampled rocks.

Table 1: Showing the locations, GPS readings and mineralogy of sampled rocks around Ikare

Sample No	Sample Name	Location	Sample type	GPS location	Mineral Assemblage
1.	Ni.1a	Near Police Station, Ikare	Grey Gneiss	N 07^{0} 30.191′ E 05^{0} 45.137′	Qtz + Bt +Plag+ Kfs + Hbl + Ap + Mt + Ilm + Zr
2.	Ni.1b	Near Police Station, Ikare	Granite Gneiss	N 07^{0} 30.028′ E 05^{0} 46.136′	Qtz + Bt + Plag + Kfs + Hbl +Ap +iIm + Mt + Zr
3.	Ni.1c	Near Police Station, Ikare	Grey Gneiss	N 07^{0} 30.191′ E 05^{0} 46.137′	Qtz + Bt+ Plag+ Kfs + Hbl + Ap + Mt + Ilm + Zr
4.	Ni.1d	Near Police Station, Ikare	Grey Gneiss	N 07^{0} 30.191′ E 05^{0} 45.137′	Qtz + Bt+ Plag+ Kfs + Hbl + Ap + Mt + Ilm + Zr
5.	Ni.2a	Near Victory College, Ikare	Patchy Charnockite in Grey Gneiss	N 07^{0} 32.281′ E 05^{0} 46.176′	Qtz + Plag + Kfs + Bt + Opx + Ap +Zr + Mt + Ilm + Py + Cp
6.	Ni.2b	Near Victory College, Ikare	Patchy Charnockite in Grey Gneiss	N 07^{0} 32.281′ E 05^{0} 46.176′	Qtz + Plag + Kfs + Bt + Opx + Hbl + Ap + Zr + Mt + Py.
7.	Ni.2c	Near Victory College, Ikare	Grey Gneiss without Patchy Charnockite	N 07^{0} 32.281′ E 05^{0} 46.176′	Qtz + Plag + Kfs + Bt + Hbl + Ap + Zr + Mt + Py.
8.	Ni.3a	Igbira Village along Ugbe - Iboropa road	Pelitic gneiss	N 07^{0} 32.731′ E 05^{0} 49.183′	Qtz + Plag + Kfs+ +Bt + Grt + Crd + Ap + Zr + ilm +Sill
9.	Ni.3b	Igbira Village Along Ugbe-Iboropa road	Pelitic gneiss	N 07^{0} 32.751′ E 05^{0} 49.187′	Qtz + Plag + Kfs + Bt + Opx + Grt + Sill + Ap + Zr + Mt + Ilm
10.	Ni.3c	Igbira Village Along Ugbe-Iboropa road	Pelitic gneiss	N 07^{0} 32.751′ E 05^{0} 49.188′	Qtz + Plag + Kfs + Bt + Opx + Grt + Sill + Ap + Zr + Mt + Ilm
11.	Ni.4	River Channel Along Imo-Agbaluku- Arigidi road	Charnockite garnetiferous	N 07^{0} 33.494′ E 05^{0} 46.405	Qtz + Plag + Kfs + Opx + Grt + Ap + Zr+ Mt + Mz + Ilm + Rt + Py + Cpy + Ilm-Mt
12.	Ni.5	Road cut along Imo Arigidi - Agbaluku road	Pelitic Gneiss	N 07^{0} 34.019′ E 05^{0} 47.145′	Qtz + Plag + Kfs + Bt + Opx + Grt + Sill + Crd + Ap + Zr
13.	Ni.6	Road cut, along Ikaramu-Oke Agbe road	Charnockitic Gneiss	N 07^{0} 37.274′ E 05^{0} 52.044′	Qtz + Plag + Kfs + Bt + Opx + Hbl + Ap + Zr + Mt + Ilm + Mt-Ilm
14	Ni.7	Abandoned quarry, outskirt of Erusu town	Charnockitic Gneiss	N 07^{0} 35.507′ E 05^{0} 50.103′	Qtz + Plag + Kfs + Bt + Opx + Hbl + Ap + Zr + Mt + Ilm + Mt - ilm + Py + Cp
15.	Ni.8a	Near old Rest House, Oke Alabojuto, Ikare	Pelitic Gneiss	N 07^{0} 31.150′ E 05^{0} 45.040′	Qtz + Plag + Kfs + Bt + Grt + Sill + Crd + Ap + Zr
16.	Ni.8b	Near old Rest House, Oke Alabojuto, Ikare	Pelitic Gneiss	N 07^{0} 31.151′ E 05^{0} 45.042′	Qtz + Plag + Kfs + Bt + Grt + Sill + Crd + Ap + Zr
Sample No	**Sample Name**	**Location**	**Sample type**	**GPS location**	**Mineral Assemblage**
17.	Ni.8c	Near old Rest House, Oke Alabojuto, Ikare	Pelitic Gneiss	N 07^{0} 31.150′ E 05^{0} 45.045′	Qtz + Plag + Kfs + Bt + Grt + Sill + Crd + Ap + Zr
18.	Ni.9a	Within Greater Tomorrow College Arigidi Akoko	Charnockite (Igneous)	N 07^{0} 31 260′ E 05^{0} 44. 330′	Qtz + Plag + Kfs + Bt + Opx + Hbl + Ap + Zr.
19.	Ni.9b	Arigidi Akoko	Charnockite (Igneous)	N 07^{0} 31 261′ E 05^{0} 44. 333′	Qtz + Plag + Kfs + Bt + Opx + Hbl + Ap + Zr.
20.	Ni.10a	Outskirt of Ikare along Arigidi-Oke Agbe road	Granite	N 07^{0} 34.314′ E 05^{0} 45.472′	Qtz + Plag + Kfs + Bt + Hbl + Ap + Zr + Mt + Ilm.
21.	Ni.10b	Arigidi-Oke Agbe road	Granite	N 07^{0} 34.522′ E 05^{0} 45.568′	Qtz + Plag + Kfs + Bt + Hbl + Ap + Zr + Mt + Ilm.
22.	Ni.10c	Arigidi-Oke Agbe road	Granite	N 07^{0} 34.531′ E 05^{0} 46.072′	Qtz + Plag + Kfs + Bt + Hbl + Ap + Zr + Mt + Ilm.
23.	Ni.11	Road cut along Ugbe- Iboropa road	Grey Gneiss	N 07^{0} 32.417′ E 05^{0} 49.411′	Qtz + Plag + Kfs + Bt + Hbl + Ap + Zr
24.	Ni.12	Road Cut along Ise - Auga road Junction	Biotite Gneiss	N 07^{0} 31.386′ E 05^{0} 55.362′	Hbl + Plag + Kfs + Bt + Qtz + Ap + Zr + Py + Cp.

Table 1 (Cont): Showing the locations, GPS readings and mineralogy of sampled rocks around Ikare					
25.	Ni. 13	Road cut, Along Akunnu -Ayere road	Charnockitic Gneiss	N 07^0 38.534′ E 05^0 56.784′	Qtz + Plag + Kfs + Bt + Opx + Ap + Zr + Ilm + Py
26.	Ni.14	Within Akunnu- Akoko town	Charnockite (Igneous)	N 07^0 39.536′ E 05^0 59.399′	Qtz + Plag + Kfs + Bt + Opx + Hbl + Ap + Zr + Mt + Ilm + Mt-Ilm
27.	Ni.15a	Akunnu -Akoko	Charnockite (Igneous)	N 07^0 39.186′ E 05^0 59.575′	Qtz + Plag + Kfs + Bt + Opx + Cpx + Hbl + Ap + Zr + Ilm + Py
28.	Ni.15b	Outskirt of Akunnu	Charnockite (Igneous)	N 07^0 39.186′ E 05^0 57.555′	Qtz + Plag + Kfs + Bt + Opx + Cpx + Hbl + Ap + Zr + Ilm + Py
29.	Ni. 16a	East of Ikare town	Granite (Porphyritic)	N 07^0 33.085′ E 05^0 46.875′	Qtz + Plag + Kfs + Bt + Hbl + Ap + Zr + Mt + Ilm + Mt- Ilm
30.	Ni. 16b	Within Ayere town	Granite (Porphyritic)	N 07^0 43.185′ E 05^0 58.875′	Qtz + Plag + Kfs + Bt + Hbl + Ap + Zr + Mt + Ilm + Mt- Ilm + Py + Cp.
31.	Ni.17a	Within Ajowa Akoko town	Charnockite (igneous)	N 07^0 40.489′ E 05^0 53.779′	Qtz + Plag + Kfs + Bt + Opx + Hbl + Ap + Zr + Mt + Ilm- Mt + Py
32.	Ni.17b	Between Ajowa and Igashi-Eriti	Charnockite (Igneous)	N 07^0 42.586′ E 05^0 57.575′	Qtz + Plag + Kfs + Bt + Opx + Cpx + Hbl + Ap + Zr + Ilm + Py
33.	Ni.18	Near Boye 34.Guest ,House, Ikare	Granite Gneiss Garnetiferous	N 07^0 31.191′ E 05^0 45.860′	Qtz + Plag + Kfs + Bt + Grt + Ap + Zr + Mt + ilm
Sample No	**Sample Name**	**Location**	**Sample type**	**GPS location**	**Mineral Assemblage**
34.	Ni.19	Along Ugbe -Iboropa road	Charnockitic Gneiss	N 07^0 32.471′ E 05^0 48.059′	Qtz + Plag + Kfs + Bt + Hbl + Opx + Ap + Zr + Mt + Ilm + Ilm- Mt
35.	Ni.20	Outskirt of Ayere Town	Charnockitic Gneiss	N 07^0 42.283′ E 05^0 58.291′	Qtz + Plag + Kfs + Bt + Opx + Hbl + Ap + Zr + Mt + Ilm – Mt.
36.	Ni.21	Along Oke-Agbe- Oyin road	Charnockite (igneous)	N 07^0 39. 894′ E 05^0 45. 560′	Qtz + Plag + Kfs + Bt + Opx + Hbl + Ap + Zr + Mt + Ilm-Mt + Py
37.	Ni.22	North of Eriti village	Charnockite (igneous)	N 07^0 44. 500′ E 05^0 48. 000′	Qtz + Plg + Kfs + Bt + Hbl + Opx + Ap + Zr + Mt + Ilm
38.	Ni.23	Offset along Ajowa -Igashi road	Charnockitic Gneiss	N 07^0 42.102′ E 05^0 50.100′	Qtz + Plag + Kfs + Bt + Hbl + Opx+ Ap + Mt + Ilm + Zr
39.	Ni.24	NE of Eriti- Igashi village	Charnockitic Gneiss	N 07^0 44. 500′ E 05^0 50. 499′	Qtz + Kfs + Plag + Bt + Opx + Hbl + Mt + Ap + Ilm + Zr
40.	Ni.25	River channel NW of Ayere town	Granite Gneiss	N 07^0 44. 500′ E 05^0 56. 498′	Qtz + Bt + Hbl + Plag + Ap + Zr + Ilm + Mt

3. Results

Figure 3 shows the chondrite-normalized REE in selected charnockites and associated rocks in Ikare area.

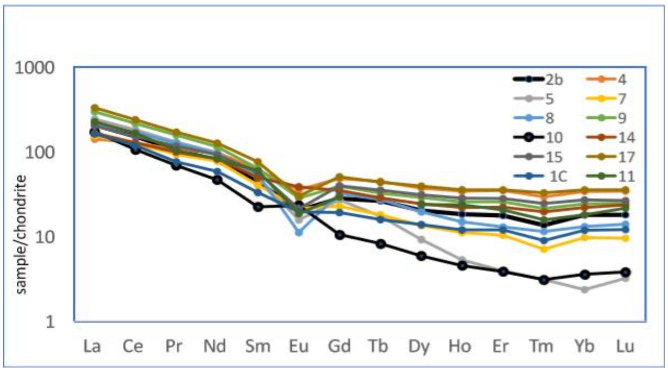

Figure 3: REE chondrite- normalized patterns for selected charnockites and associated rocks around Ikare (drawn after McDonough and Sun, 1995).

3.1 Igneous charnockites

three varieties of charnockitic rocks were sampled, namely igneous charnockite, patchy charnockite and charnockitic gneiss. All igneous charnockite examined are enriched in REE relative to chondrite abundances and compared with the average REE value of 250 ppm for granitic rocks in general (Emmermann et al., 1975). REE ranged between 203 ppm and 329 ppm with average of 278 ppm (Table 1). They showed high degree of fractionation with steep patterns, most especially the LREE (La to Sm) relative to HREE (Gd to Lu). La/Yb_N ranged between 7.54 and 12.74 (Average, 10.73). while the La/Sm_N ratios ranged from 2.29 to 6.24 (average, 4.24) (Table 2). Samples Ni.9, Ni.14, Ni.15 and Ni.17 showed pronounced negative Eu anomalies and the Eu/Eu^* values ranged from 0.44 to 0.89 (Fig.3). These negative europium anomalies are indication of feldspar fractionation, since feldspars are the only rock forming minerals enriched in Eu (Philpotts and Schnetzler, 1968; Philports, 1970). This feldspar is believed to be plagioclase feldspar (Towell et al, 1965; Condie and Lo, 1971). The REE data of Ikare igneous charnockite compare favourably with those of Rapakivi granites of Finland (Kiljonen and Rosenburg, and that of Torpa-Varberg granite in Sweden (Hubbard and Whitley, 1978, 1979; Kiljonen and Rosenburg, 1974). This further suggests that the igneous charnockite of Ikare share similar parental magma with those of Rapakivi and Torpa - Varberg granites. Igneous charnockites have high values for La (40 ppm to 80 ppm) compared to 25 ppm for average mean value of granites (Tyler, 1965). For La/Yb_N ratio, the values ranged from 7.09 to 12, with the exception of sample Ni.4, which is less than 5.0. This is evidence that the igneous charnockite around Ikare evolved through magmatic differentiation. The higher the ratios of La/Yb_N, the higher the differentiation of the source (Feng and Kerrich, 1990). Gd/Yb_N are generally low (below 2.0) for the igneous charnockites (Table 2).

Table 2: Rare earth element data (ppm) for igneous charnockite around Ikare											
Sample No. REE (ppm)	**Ni,9a**	**Ni.14**	**Ni.15**	**Ni.17**	**Ni.21**	**Ni.22**	**Ni.9b**	**Ni.15b**	**N.17b**	**N.4**	**Average**
La	72	40	49	80	75	48	47	78	80	34	60.3
Ce	137	81	97	151	80	95	138	87	130	81	80
Pr	15	9.4	11	16	15	18	16	10	15	10	13.54
Nd	54	39	43	60	55	64	54	65	60	46	49.7
Sm	10	7.6	8.3	12	7.5	7.8	10	8.2	13	9.4	9.38
Eu	1.6	2.2	1.2	1.7	2.1	1.8	1.2	1.5	1.7	2.1	1.71
Gd	8.0	7.1	8.1	10	8.5	8.0	7.2	7.3	10	9.8	8.40
Tb	1.2	1.1	1.3	1.6	1.3	1.6	1.3	1.1	1.8	1.6	1.40
Dy	7.3	6.2	7.8	9.9	7.6	9.7	6.5	6.8	7.8	9.4	8.00
Ho	1.5	1.2	1.6	2.0	1.7	2.0	1.6	1.5	1.4	1.9	1.64
Er	4.2	3.6	4.6	5.9	3.8	4.5	4.8	4.7	3.7	5.8	4.56
Tm	0.55	0.51	0.63	0.85	0.56	0.55	0.51	0.54	0.51	0.76	0.60
Yb	4.0	3.6	4.4	5.8	4.0	3.8	4.5	3.8	3.7	5.6	4.32
Lu	0.61	0.59	0.66	0.89	0.62	0.58	0.70	0.61	0.67	0.85	0.67
∑REE	317	203.1	238.6	357.6	262.7	265.3	293.3	276.1	329.3	218.3	278.75
La/Yb_N	12.23	7.54	7.56	9.37	12.74	8.58	7.09	13.9	14.6	4.12	10.3
La/Sm_N	4.50	3.28	3.68	4.16	6.24	3.84	2.93	5.94	6.09	2.25	4.02
Gd/Yb_N	1.61	1.59	1.59	1.39	1.72	1.70	1.29	1.55	1.55	1.41	1.57
Eu/Eu^*	0.52	0.89	0.44	0.46	0.80	0.80	0.41	0.57	0.43	0.66	0.57

3.2 Granites

Table 3 shows the rare earth element (ppm) data for the granites studied. The total REE ranged between 141.41 and 157.46. These values are lower than those obtained for igneous charnockites and less than average value of 250 ppm for granitic rocks in general (Emmermann et al.,1975) (Table 1). La values ranged from 40 ppm to 47 ppm less than average value of 60.3 obtained for igneous charnockite (Table 1). Like igneous charnockites, the granites display enchrichment in the LREE and depletion in HREE. The La/Yb_N ratios ranged between 46.85 and 54.44 with average value of 50.37. These values are higher than those of igneous charnockites with average value of 10.3 (Table 2). The Gd/Yb_N ratios are generally above 2.0. The Eu/Eu^* ranged between 1.20 and 1.54 with average value of 1.45.

Table 3: Rare earth element data (ppm) for the granite around Ikare						
Sample No REE (ppm)	**Ni.10a**	**Ni.10b**	**Ni.10c**	**Ni.16a**	**Ni.16b**	**Average**
La	42	40	42	47	44	43
Ce	67	68	67	65	67	66.80
Pr	6.6	6.5	5.8	7.1	6.6	6.52
Nd	22	23	25	21	28	23.80
Sm	3.40	3.30	3.70	3.00	3.40	3.36
Eu	1.30	1.30	1.20	1.30	1.50	1.32
Gd	2.10	2.00	2.10	2.30	2.30	2.16
Tb	0.3	0.32	0.31	0.36	0.3	0.31
Dy	1.5	1.5	1.6	2.0	1.8	1.68
Ho	0.26	0.26	0.25	0.30	0.25	0.26
Er	0.64	0.68	0.66	0.64	0.67	0.65
Tm	<0.1	1	1	<0.1	1	1
Yb	0.59	0.58	0.59	0.60	0.55	0.58
Lu	0.59	0.07	0.10	0.07	0.09	0.08
∑REE	147.78	148.51	151.31	150.67	157.46	151.52
La/Yb_N	49.20	46.85	48.41	53.31	54.44	50.37
La/Sm_N	7.71	7.57	7.08	9.78	8.08	8.00
Gd/Yb_N	2.92	2.79	2.88	3.10	3.38	3.01
Eu/Eu^*	1.37	1.42	1.20	1.45	1.54	1.39

3.3 Patchy charnockite and charnockitic gneiss

The REE distribution patterns for selected samples from patchy charnockite and gneissic charnockite (Ni.2b and Ni.7) are shown in Figure 3. The patchy charnockites have lower absolute REE abundances than gneissic charnockites. These values ranged from 207.3ppm to 226.7ppm for three samples of patchy charnockite, while those of gneissic charnockite ranged from 183.3 to 357.6 ppm (Tables 4 and 5). However, on the REE-Chondrite normalized diagram, drawn after McDonough and Sun, patchy charnockite (Ni.2b) did not show pronounced Eu anomaly unlike that of the charnockitic gneiss (Ni.7) (McDonough and Sun, 1995). La values ranged from 45 ppm to 51 ppm for patchy charnockite and 38 ppm to 80 ppm for gneissic charnockites. These values are above the average mean value of 25 ppm in granite and above average mean value of 20 ppm in shale (Tyler, 1965; Haskin et al., 1968). Like the igneous charnockites, La/Yb_N ratios for patchy and gneissic charnockites are above 5.0. It ranged from 8.25 to 11.95 for patchy and 5.46 to16.14 for the gneissic charnockites, therefore indicating that their precursors must have evolved through magmatic differentiation (Tables 4 and 5). Both patchy charnockite and gneissic charnockite display relatively smaller negative Eu anomalies (0.46 to 0.89), probably due to insignificant role that feldspar fractionation played during the evolution of these rocks.

Table 4: Rare earth element data (ppm) for the patchy charnockite around Ikare

Sample No. REE (ppm)	Ni. 2a	Ni.2b	Ni.2c	Average
La	45	51	56	50.6
Ce	80	96	92	89.3
Pr	10	10	9	9.6
Nd	42	37	38	39
Sm	6.8	6.7	6.4	6.6
Eu	1.2	1.2	1.2	1.2
Gd	9	5.7	5.5	6.8
Tb	1.3	1.0	1.0	1.1
Dy	3.5	5.1	7.5	5.3
Ho	1.5	1.0	1.2	1.2
Er	2.8	2.9	3.5	3.0
Tm	0.17	0.35	0.60	0.37
Yb	3.7	2.90	4.2	3.6
Lu	0.30	0.45	0.62	0.45
∑REE	207.3	221.3	226.7	218.4
La/Yb_N	8.25	11.95	9.08	9.76
La/Sm_N	4.13	4.75	5.46	4.78
Gd/Yb_N	1.96	1.59	1.06	1.53
Eu/Eu^*	0.46	0.57	0.60	0.54

Table 5: Rare earth data (ppm) for the charnockitc gneiss around Ikare

Sample No. REE (ppm)	Ni. 6	Ni.7	Ni. 13	Ni. 19	Ni. 20	Ni.23	Ni.24	Average
La	45	38	40	49	80	70	46	51.7
Ce	78	79	81	97	151	150	96	104.5
Pr	10	8.9	9.4	11	16	15	12	11.7
Nd	39	37	39	43	60	42	38	42.5
Sm	7.5	6.2	7.6	8.3	12	6.5	8.2	8.0
Eu	1.5	1.2	2.2	1.2	1.7	1.3	1.2	1.47
Gd	7.0	4.6	7.1	8.1	10	4.0	4.5	6.4
Tb	1.5	0.66	1.1	1.3	1.6	1.2	1.1	1.2
Dy	6.5	3.4	6.2	7.8	9.9	7.5	6.4	6.8
Ho	2.0	0.63	1.2	1.6	2.0	1.2	0.65	1.32
Er	5.7	1.7	3.6	4.6	5.9	4.5	5.8	4.54
Tm	0.17	0.18	0.51	0.63	0.85	0.18	0.62	0.44
Yb	5.6	1.6	3.6	4.4	5.8	5.5	3.5	4.28
Lu	0.60	0.24	0.59	0.66	0.89	0.47	0.25	0.52
∑REE	210.1	183.3	203.1	238.6	357.6	309.4	224.7	246.6
La/Yb_N	5.46	16.14	7.54	7.56	9.37	8.64	8.92	9.09
La/Sm_N	3.74	3.82	3.28	3.68	4.16	6.72	3.50	4.12
Gd/Yb_N	1.01	2.32	1.59	1.49	1.39	0.58	1.04	1.34
Eu/Eu^*	0.62	0.65	0.89	0.44	0.46	0.72	0.54	0.61

3.4 Grey and Granite gneisses

Table 6 shows the rare earth element (ppm) data for the grey and granitic gneisses. For the grey gneisses, La values ranged between 42 ppm and 55 ppm, while the granite gneisses ranged between 45 ppm and 58 ppm. Like the charnockitic rocks, La values are higher than mean average value of 25 ppm for granite (Tyler,1965). Total REE for the grey gneisses ranged from 169.6 to 243.1 and that of granite gneisses ranged from 188.6 to 216.7. From this result, it can be shown that igneous charnockites are more enriched in rare earth elements than these gneisses and other varieties of charnockite in the studied area (Tables 2, 4, 5 and 6). Also, the

La/Yb_N ratio ranged between 12.88 to 16.79 for grey gneisses and 11.32 to 23.19 for the granite gneisses (Table 6). These values are slightly higher than those of the charnockites and more than 5.0. Therefore, it can be suggested that the protoliths of these gneisses must have evolved through magmatic differentiation similar to those of the charnockites. (Feng and Kerrich, 1990). The average Gd/Yb_N ratios for the gneisses are below 2.0, similar to the charnockitic rocks (Table 6). From the REE chondrite normalized diagram for selected rock samples, the gneisses (Ni 1c and Ni.11) display pronounced Eu anomalies (Figure 3). The gneisses also exhibit enrichment in LREE and depletion of HREE. The Eu/Eu* values are less than 1.0 for all samples (average value of 0.59) (Table 6). These values compare favourably with those obtained by Olarewaju for charnockites in Ikerre-Akure area. Also, the values are similar to those recorded for Rapakivi granite in Finland and Torpa -Varberg charnockite granite association in southwestern Sweden (Koljonen and Rosenberg, 1974; Hubbard and Whitley, 1978).

Table 6: Rare element data (ppm) for the grey and granite gneisses around Ikare

Sample No.	Ni.2a	Ni.2b	Ni.2c	Ni.6	Ni.7	Ni.13	Ni.19	Ni.20	Ni.23	Ni.24	Av.
REE (ppm)											
La	45	51	56	45	38	40	49	80	70	46	52
Ce	80	96	92	78	79	81	97	151	150	96	100
Pr	10	10	9	10	8.9	9.4	11	16	15	12	11.1
Nd	42	37	38	39	37	39	43	60	42	38	41.5
Sm	6.8	6.7	6.4	7.5	6.2	7.6	8.3	12	6.5	8.2	7.62
Eu	1.2	1.2	1.2	1.5	1.2	2.2	1.2	1.7	1.3	1.2	1.4
Gd	9	5.7	5.5	7.0	4.6	7.1	8.1	10	4.0	4.5	6.5
Tb	1.3	1.0	1.0	1.5	0.66	1.1	1.3	1.6	1.2	1.1	1.1
Dy	3.5	5.1	7.5	6.5	3.4	6.2	7.8	9.9	7.5	6.4	6.3
Ho	1.5	1.0	1.2	2.0	0.63	1.2	1.6	2.0	1.2	0.65	1.3
Er	2.8	2.9	3.5	5.7	1.7	3.6	4.6	5.9	4.5	5.8	4.1
Tm	0.17	0.35	0.60	0.17	0.18	0.51	0.63	0.85	0.18	0.62	0.42
Yb	3.7	2.9	4.2	5.6	1.6	3.6	4.4	5.8	5.5	3.5	4.08
Lu	0.30	0.45	0.62	0.60	0.24	0.59	0.66	0.89	0.47	0.25	0.50
∑REE	207.3	221.3	226.7	210.1	183.3	203.1	238.6	357.6	309.4	224.7	238.1
La/Yb_N	8.25	11.95	9.08	5.46	16.14	7.54	7.56	9.37	8.64	8.92	9.29
La/Sm_N	4.13	4.75	5.46	3.74	3.82	3.28	3.68	4.16	6.72	3.50	4.32
Gd/Yb_N	1.96	1.59	1.06	1.01	2.32	1.59	1.49	1.39	0.58	1.40	1.40
Eu/Eu*	0.46	0.57	0.60	0.62	0.65	0.89	0.44	0.46	0.72	0.54	0.59

Av. – Average

3.5 Pelitic gneisses

Table 7 show rare earth element data for the pelitic gneisses. The metapelites are generally richer in REE than the charnockites studied in this work. The total REE varied from 252 to 259.24 (Table 7). La/Yb_N ranged between 19.41 and 82.04 with average value of 40.06. Gd/Yb_N ratios are above 1.0. However, the Eu/Eu* ratio ranged from 0.22 to 0.44. Like other rock types, they display enrichment in LREE and depletion in HREE.

Table 7: Rare earth element (ppm) data for the pelitic gneiss around Ikare

Sample No.	Ni. 3a	Ni. 3b	Ni. 3c	Ni. 5	Ni. 8a	Ni. 8b	Ni. 8c	Average
REE (ppm)								
La	60	57	59	52	70	58	65	60.1
Ce	118	105	115	107	108	115	120	112.5
Pr	11	12	12	12	12	14	12	12.1
Nd	48	45	46	45	46	48	42	45.7
Sm	6.3	6.4	7.6	8.3	7.5	7.0	8.2	7.3
Eu	0.90	0.80	0.91	0.60	0.91	0.50	0.71	0.76
Gd	5.7	6.3	5.5	6.5	5.0	6.4	6.5	5.9
Tb	1.0	0.60	0.64	1.0	1.0	0.62	1.0	0.83
Dy	2.4	3.7	2.3	4.9	4.8	4.5	2.2	3.54
Ho	0.70	0.80	0.30	0.84	0.60	0.30	0.74	0.61
Er	1.8	0.49	0.48	2.10	2.00	0.48	2.10	1.35
Tm	0.28	0.29	< 0.01	0.29	0.30	0.20	< 0.01	0.27
Yb	2.1	0.53	0.59	2.10	0.58	0.55	0.70	1.02
Lu	0.30	1.00	0.09	0.35	0.34	0.08	0.09	0.32
∑REE	258.48	239.91	250.41	242.98	259.03	255.63	259.24	252.30
La/Yb_N	19.41	73.10	68.01	16.37	82.04	71.76	63.19	40.06
La/Sm_N	5.94	5.56	4.84	3.91	5.82	5.17	4.95	5.14
Gd/Yb_N	2.19	9.61	7.55	2.50	6.97	9.43	7.51	4.68
Eu/Eu*	0.44	0.38	0.38	0.24	0.42	0.22	0.28	0.34

4. Discussion

Generally, the charnockites and other rock types have rare earth elements characterized by (i) LREE enrichment which is known for crustal and calc-alkaline rocks in general (ii) Negative europium anomalies are prominent in the charnockitic and associated rocks of the studied area (O'Nions and Pankhurst, 1974). (iii) varying degrees of depletion in heavy rare element (HREE) (iii) The rare earth element distribution patterns showed a typical continental crust behavior (Rudnick and Fountain, 1995). The rocks generally showed significant europium anomalies due to previous segregation of Ca-rich phases such as Ca-rich plagioclase for a magmatic origin or Ca-poor protolith in case of the pelitic gneisses. Igneous charnockite are more enriched in REE than other varieties of charnockites while, granites and gneisses except the pelitic ones have the lowest concentration. The values obtained for the charnockitic rocks compared favourably with those of Rapakivi granites in Finland and Torpa-Varberg charnockite-granite association in Sweden (Table 8). The moderate La/Yb_N in the I-type felsic rocks amidst relatively high $(HREE)_N$ values of some of the samples point to absence of garnet in the source. Therefore, if a mantle source is imagined, the source should be a spinel-bearing mantle. If partial melting is assumed, the lower crustal basic rocks or subducted slabs should also be poor in garnet (Barker and Arth, 1976). The relatively high LREE observed in charnockites and associated rocks around Ikare are due to fractionation and probably crustal contamination.

Table 8: Rare earth element data (ppm) of rock used for comparison (after Olarewaju, 1988)

REE(ppm)	1	2	3	4	5	6	7	8	9	10
La	146.0	123	152	52.3	196	77.20	57.50	81.7	49.0	6.50
Ce	269.0	270	334	118.0	388	155.0	102.3	159.0	90.40	20.8
Nd	78	100	106	47	159	70.3	57.30	66.00	51.30	
Sm	16	12.6	17	8.0	29.0	18.4	9.80	14.90	12.00	3.80
Eu	0.32	1.23	2.20	0.70	2.08	3.00	2.50	3.17	1.18	1.14
Gd				5.70	24.5		13.60	19.40	12.70	
Tb	1.60	3.00	1.90	0.60		1.90	1.30		1.69	0.37
Ho				0.50						
Tm								2.25	0.84	
Yb	6.30	9.00	5.70	1.00	8.77	6.50	4.10	13.80	6.07	1.20
Lu	1.23	1.62	0.90		51.1	1.00	0.80	1.91		0.14
REE	519.05	525.45	619.70	233.8	859.2	333.3	249.2	363.2	225.1	33.9

1 = Rapakivi granite (even grained), Kalanti, Finland (Koljonen and Rosenburg, 1974)

2 = Rapakivi granite (Wiborgite), Lapinjarvi, Finland (Koljonen and Rosenberg, 1974)

3 = Torpa granite, SW Sweden (Hubbard and Whitley, 1978) (3 analyses)

4 = Average of 2 coarsely porphyritic biotite granite (de Albuquerque, 1978)

5 = Biotite granite, north east Brazil (Sial et., 1981)

6 = Average of 9 charnockitic phases of charnockite – granite association, SW Sweden (Hubbard and Whitley,1978)

7 = Average of 4 massive charnockites, Sao Paulo, Brazil (Gasparini and Mantovani, 1979)

8 = Acid charnockite MP45 from Madras (Weaver, 1980)

9 = Basic granulite MP11 from Madras (Weaver, 1980)

10 = Basic charnockites (6 analysese) from French Massif (Dupay et al., 1979)

5. Conclusion

The charnockites and associated rocks of Ikare area have high absolute REE values which are typical of lower continental crust. Despite lack of geochronological data, one probable model for crustal formation based on the REE data suggests that magmatic precursors (apart from pelitic gneisses) of igneous and gneissic charnockites intruded in quick succession as a larger intrusion sequence into a crust of already metamorphosed sediments and protoliths of the grey and granite gneisses. This is supported by relatively similar REE patterns of the granitic and charnockitic gneisses.

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References

Albuquerque, C.A.R. de. 1978. Rare earth elements in Younger granite northern Portugal. Lithos, 11, Pp. 219 - 229.

Barker, F., Arth, J.G., 1976. Generation of trondhjemite tonalitic liquids and Archean bimodal trondhjemite basaltic suites. Geology, 4, Pp. 596-600.

Condie, K.C., Lo, H.H., 1971. Trace element geochemistry of the Louis Lake batholiths of early Precambrian age. Wyoming Geochim. Cosmochim Acta, 35, Pp. 1099-1119.

Emmermann, R., Daieva., L, Schneider, J., 1975. Petrologic significance of rare earths distribution in granites. Contribution to Mineralogy and Petrology, 52, Pp. 267-283.

Feng, R., Kerrich, R., 1990. Geochemistry of fine-grained clastic sediments in the Archean –Abitibi greenstone belt, Canada: Implication for provenance and tectonic setting. Geochimica Cosmochimica Acta, 54, Pp. 1061-1081.

Hanson, G.N., 1980. Rare earth elements in petrogenetic studies of igneous systems. Am. Rev. Earth Planet. Science Letters, 42, Pp. 311-320.

Haskin, L.A., Haskin., M.A., Frey, F.A., Widerman, T.R., 1968. Relative and absolute terrestrial abundances of the rare earths in origin and distribution of the elements (ed) L.H. Adams., 30, Pp. 889 - 912, Pergmon Press, Oxford, London.

Hubbard, F.H., Whitley, 1978. Rapakivi granite, anorthosites and charnockitic plutonism. Nature, 271, Pp. 439-440.

Hubbard, F.H., Whitley, 1979. REE in charnockitic and associated rocks, southwestern Sweden. Lithos, 12, Pp. 1-11.

Koljonen, T., Rosenburg, R.J., 1974. Rare earth elements in granitic rocks. Lithos, 7, Pp. 249-261.

McDonough, W.F., Sun, S.S., 1995. The composition of the Earth. Chemical Geology 120, Pp. 223-253.

Olarewaju, V.O., 1988. REE in charnockitic and associated rocks of Ado Ekiti – Akure, southwestern Nigeria. In P.O. Oluyide et al., Precambrian Geology of Nigeria. A publication of Geological Survey of Nigeria, 231-239.

O'Nions, R.K., Pankhurst, R.J., 1974. Rare earth element distribution in Archean gneisses and anorthosites, Godthab area, West Greenland. Earth Planetary Science letters, 22, Pp. 328-338.

Philports, J.A., 1970. Redox estimation from a calculation of Eu 2+ and Eu

3+ concentration in natural phases. Earth Planetary Science Letters, 9, Pp. 257-268.

Philports, J.A., Schnetzler, C.C., 1968. Europium anomalies and the genesis of basalt. Chemical Geology, 3, Pp. 5-13.

Rudnick, R.L., Fountain, D.M., 1995. Nature and composition of the continental crust: a lower crustal perspective, review in Geophysics, 33 (3), Pp. 267-309.

Sial, A.N., Figuereds, M.C.H., Long, L.E.I., 1981. Rare earth element geochemistry of the Mernoca and Mucombo plutons Ceara, Northern Brazil. Chemical Geology, 31, Pp. 271-283.

Towell, D.G., Winchester, J.W., Spira, R.V., 1965. Rare earth element distributions in some rocks and associated minerals of the batholiths of Southern California. Journal of Geophysical Research, 70, 3485-3496.

Tyler, G., 2004. Rare earth elements in soil and plant systems: a review plant and soil, 267, Pp. 191.

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