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RESEARCH ARTICLE

RETROGRESSION OF ORTHOPYROXENE – BEARING CHARNOCKITIC GNEISS AROUND IKERAM-IBARAM AKOKO, SOUTHWESTERN NIGERIA

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ABSTRACT

This paper presents the petrography and mineral chemistry of charnockitic gneisses exposed at Ikeram-Ibaram within the Precambrian Basement Complex of southwestern Nigeria. Quartz, plagioclase, perthite, amphibole, biotite and orthopyroxene are essential minerals, while apatite, ilmenite, magnetite and zircon are accessories. Orthopyroxene is ferro-hypersthene ($En_{44}Fs_{56}Wo_0$) with low TiO_2, CaO contents, but high in MgO compositions. Orthopyroxene is mantled by hornblende and relicts of biotite grains are found within orthopyroxene as inclusions. Plagioclase is andesine and occur as inclusions in other minerals. Biotite has high concentration of TiO_2, but poor in CaO. Ilmenite and magnetite are closely associated with orthopyroxene. Rare earth element (REE) displays enrichment in light REE and depletion in heavy REE with negative Eu anomaly. Biotite as relicts in orthopyroxene and amphibole mantling orthopyroxene are clear evidences of retrograde metamorphic events. The mineral reactions suggest the retrogression of the charnockitic gneisses that are products of rehydration processes. These relationships between pairs of minerals indicate retrogressive form of metamorphism at the transition from granulite facies to amphibolites facies.

KEYWORDS

ferro – hypersthene, rehydration, retrograde event, rare earth element, granulite.

1. INTRODUCTION

Pyroxen**e –** bearing gneisses are often referred to as charnockitic gneisses, especially when they contain hypersthene. The word "charnockite" was first introduced by Holland to honour Job Charnock (founder of Calcutta, India) whose tombstone was made of the rock (Holland, 1900). He defined charnockite as quartzo- feldspar – hypersthene – iron ore rock. Charnockites are orthopyroxene – bearing anhydrous granitoids (Holland, 1900; Le Maitre, 2002). They occur as patches in host gneisses, magmatic and metamorphic in origin, Charnockites are restricted to high grade granulite terrains and in cases associated with rocks of amphibolites facies. They are formed from both igneous and sedimentary protoliths during high grade metamorphism under low activity of water (Rajesh et al., 2012). Parras described an orthopyroxene – garnet bearing dark greenish metamorphic rock of zones of dehydration as "incipient charnockite" similar to the rock observed (Holland, 1900; Parras, 1958).

These rocks were found to occur in many parts of southern India and the world. Pichamuthu opined that original protolith was dehydrated by influx of CO_2 released from underplated basalts or carbonates (Pichamuthu, 1960). Harlov considered influx of external fluid, preferably of low a- H_2O during granulite metamorphism as the main cause of charnockitisation (Harlov, 2012). A group researcher attributed the retrogression of pyroxene bearing gneiss of Iboropa Akoko, southwestern Nigeria to retrograde metamorphic event (Oziegbe et al., 2020). Some researcher also, documented the occurrence of dehydrated charnockite of North China Shield and concluded that they were formed at ultra – high temperature conditions of about 890⁰ - 970⁰C (Yang et al., 2014). In this research, the study area, Ikeram – Ibaram is underlain by rocks of the southwestern Basement Complex.

The rocks consist of migmatite –gneiss – quartzite complex, with charnockites and granites occurring as enclaves. The migmatitic gneisses of this area are composed of three components, which in most cases occur in same outcrop. These components are the paleosome (early gneiss), leucosome (granite and/ or granite gneiss) and neosome (amphibolites bands). Ikeram – Ibaram is about 9km north of Ikare. The charnockitic gneiss of Ikeram – Ibaram is dark grey and foliated. Rahaman and Ocan worked on the nature of granulite metamorphism of Ikare area, but devoid of micro-chemical data (Rahaman and Ocan, 1988). Therefore, this paper is aimed at presenting the petrography, mineral chemistry as well as bulk rock geochemistry of the charnockitic gneisses as exposed at Ikeram – Ibaram, southwestern Nigeria.

2. LOCATION AND ACCESSIBILITY OF THE STUDY AREA

The study area, Ikeram - Ibaram Akoko is situated in the northernmost part of Ondo State, southwestern Nigeria. It lies within latitudes 7⁰ 35′ – 7⁰ 38′N and longitudes 5⁰ 48′ – 5⁰ 55′E (Figure 1). The area is linked up with motorable roads from neighbouring towns like Erusu, Oke Agbe, Akunnu Akoko and Ajowa. There are numerous footpaths which makes traversing easier. The relief is rugged and marked by rocky undulating hills of migmatites, charnockites and other gneissic rocks. The area is well drained by rivers and streams. Drainage pattern is dendritic and controlled by the underlying lithology and geological structures. The climate is of Tropical rain forest characterized by two alternating seasons

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of wet and dry (Iloeje, 1976). The wet season covers the period between mid-March to October having a break in August, while the dry season starts in November and ends mid-March. Temperatures are constantly high with average minimum of about 32^{0}C in February and March to minimum of 21^{0}C in August. Heavy rainfall and extreme temperatures are likely to enhance weathering of rocks. Figure 1 shows the location map and sampling points of the rocks used in this study.

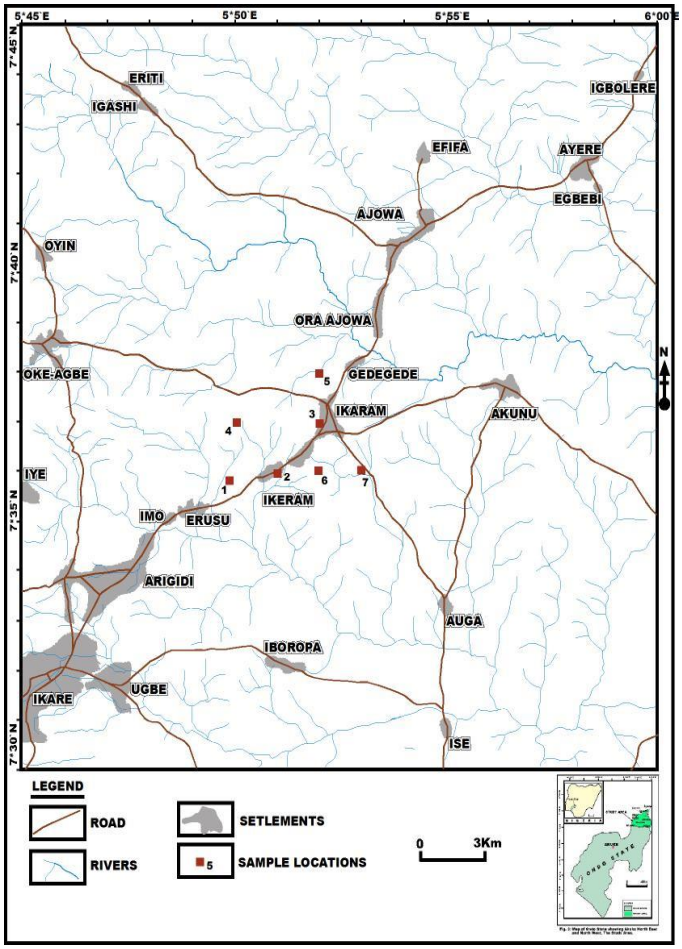

Figure 1: Location map of study area and sampling points

3. Materials and Methods

Detailed geological mapping of the area was carried out on topographical map tagged "Ikole S.E sheet no. 245. Fresh representative samples (7) were collected and well labeled. Chip rock samples were made into thin and polished sections for petrographic studies under petrological microscope marked LEICA DMRXP and Scanned Electron Microscope (SEM) housed at the Institute of Earth and Environmental Science, Universität, Potsdam, Germany. Major elements and trace elements were determined at same Institute, using X-ray Fluorescence (XRF) and ICP-AES (Inductively Coupled Plasma – Atomic Emission Spectrometer) respectively. The micro-chemical analysis was carried out using electron microprobe analyzer (JEOL JSM 6510) at the Institute of Earth and Environmental Science, Potsdam, Germany. Equipment was operated at the voltage of acceleration of 15 Kv at regulated beam of 15n A. Electron beams were 1µm in size. Natural standards were adopted for measuring X-rays and ZAF matrix correction methods used for quantification purposes.

4. Results

4.1 Petrography

Petrographic study on charnockitic gneiss revealed that the assemblages of mineral are plagioclase, quartz, hornblende, biotite, alkali-feldspar, orthopyroxene , while the accessory minerals are ilmenite, apatite, magnetite, pyrite, chalcopyrite and zircon. On the field, the charnockitic gneiss display strong foliation (Figure 2). Alteration textures are myrmekite intergrowth and anti-perthite (Figure 3). Biotite is reddish brown, strongly pleochroic from yellow to deep brown. Pleochroic haloes common around small inclusions of zircon. Opaques are closely associated with orthopyroxene and biotite, probably involved in orthopyroxene

Figure 2: Field photograph showing an outcrop of charnockitic gneiss at the outskirt of Ikeram-Akoko.

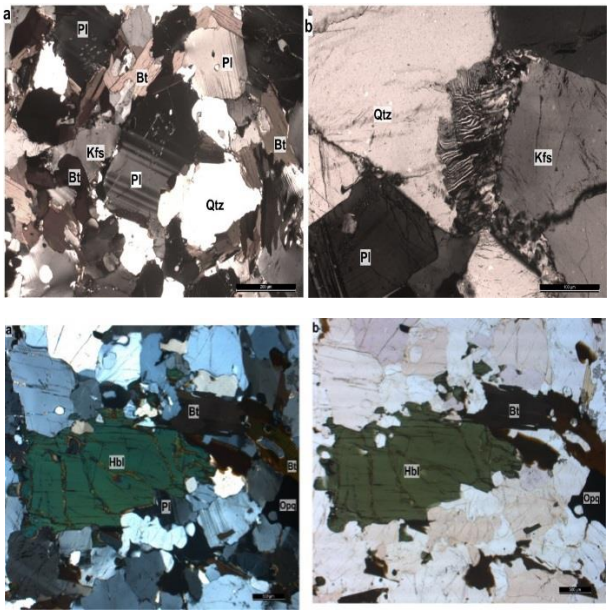

Figure 3: Photomicrographs showing (a) anti-perthite and perthite textures and (b) myrmekite at boundary of alkali-feldspar and quartz.(c &d) numerous cracks in amphibole (hornblende)

Producing reactions. Hornblende minerals are cracked and closely associated with dark brownish biotite grains (Figure 3). Skeletal biotite grains within orthopyroxene are probably biotite relics left behind after their decomposition to form orthopyroxene in the presence of quartz (Figure 4). Back scattered electron images showed pyroxene (orthopyroxene) enclosed by amphibole (hornblende) which suggest retrograde metamorphic event (Figure 5). Figure 6 shows areal analysis of ex-solution of K-feldspar in plagioclase and inclusions of magnetite in plagioclase. The petrography observed in the thin sections were confirmed by the scanned electron microscope (SEM) backscattered electron image of the rock from which the mineral chemistry were determined subsequently.

4.2 Mineral chemistry

4.2.1 Pyroxene

There is slight variation in the mineral composition of the pyroxene in the charnockitic gneiss from the core to rim (Table 1). The range in composition for both the core and rim is: SiO_2: 48.96 – 50.66%%; MgO: 13.18 – 16.07%; FeO: 30.12 – 35.19% and CaO: 0.54 – 1.03%. This shows that the orthopyroxene in the charnockitic gneiss varies from hypersthenes to ferro-hypersthene. The recalculated formula can be expressed as $Fs_{56}En_{44}Wo_0$ for core composition (Table 1).

4.2.2 Amphibole

The mineral composition of amphibole is presented in Table 2. SiO_2: 40.55 – 41.90%; TiO_2: 1.08 – 1.52%; FeO: 21.16 – 21.84%; Al_2O_3: 10.65 – 11.37%; MgO; 7.66 – 8.42%; CaO; 10.91 – 11.42%, Na_2O; 1.32 – 1.60% and K_2O: 1.31 – 1.70% for both core and rim compositions. The compositional range shows that Fe, Ca and Mg have higher values compared to low amount of sodium (Na), which is characteristic of hornblende. Therefore, the amphibole in the charnockitic gneiss is hornblende (pargasitic in compostion).

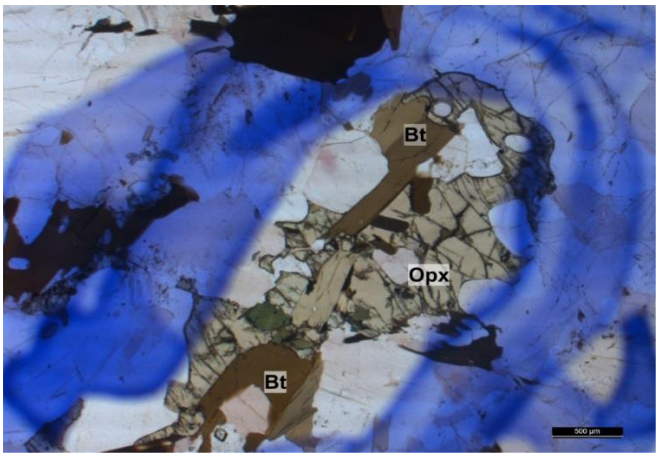

Figure 4: Photomicrograph showing ample evidence of breakdown of biotite to form orthopyroxenein charnockitic gneiss under plane polarized light.

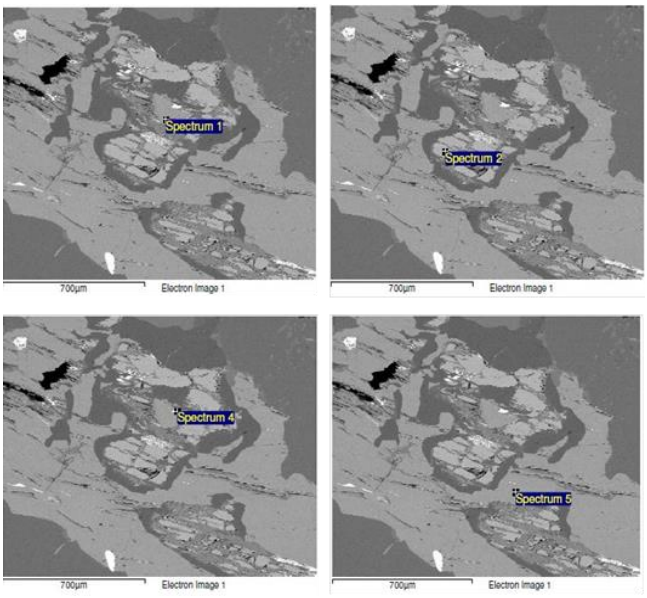

Figure 5: BSE images showing amphibole around orthopyroxene (Spectrum 1), orthopyroxene (Spectrum 2) and magnetite in amphibole (Spectrum 4) and core of amphibole (Spectrum 5) in charnockitic gneiss of Ikeram Akoko.

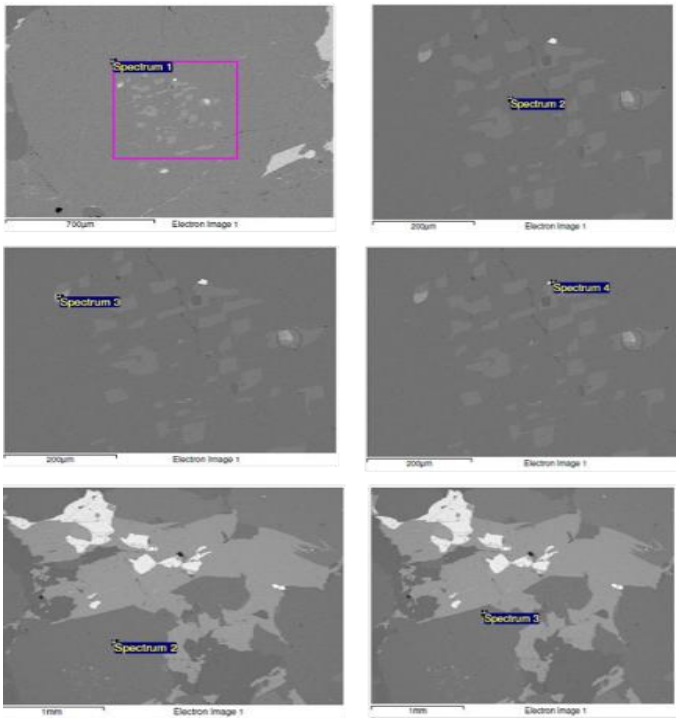

Figure 6: (a) Areal analysis of plagioclase centre with exolutions (Spectrum 1), (b) K-feldspars exolutions in plagioclase (spectrum 2), (c) biotite inclusion in plagioclase (Spectrum 3), (d) magnetite in plagioclase (Spectrum 4), (e) plagioclase (andesine) core (spectrum 2) and plagioclase (andesine) rim (spectrum 3) in charnockitic gneiss around Ikeram Akoko.

Table 1: Representative microprobe data of orthopyroxene in the charnockitic gneiss								
Oxides (wt%)	**core**	**rim**	**core**	**rim**	**core**	**rim**	**core**	**rim**
SiO_2	48.96	49.05	49.30	49.90	50.34	50.66	50.45	50.37
TiO_2	0.06	0.06	0.07	0.05	0.06	0.04	0.07	0.03
Al_2O_3	0.57	0.56	0.60	0.81	0.81	0.68	0.878	0.80
FeO	34.55	34.61	35.19	35.03	30.98	30.38	30.55	30.12
MnO	2.31	2.25	2.18	2.13	1.83	1.78	1.85	1.72
MgO	13.45	13.65	13.18	13.39	15.47	15.65	16.07	15.99
CaO	0.83	1.03	0.79	0.57	0.90	0.65	0.75	0.54
Na_2O	0.04	0.05	0.05	0.06	0.04	0.01	0.04	-
K_2O	0.01	0.01	-	-	0.01	0.02	0.01	0.03
Sum	**100.78**	**101.27**	**101.36**	**101.94**	**100.44**	**99.87**	**100.66**	**98.88**
Structural formula recalculated based on 4 cations and 6 oxygens								
Si	1.91	1.92	1.94	1.96	1.97	1.96	1.95	1.97
Al (iv)	0.03	0.03	0.03	-	-	-	0.04	0.03
Fe^{3+}	0.15	0.14	-	0.08	0.05	0.01	0.06	0.03
Fe^{2+}	0.98	1.00	0.10	1.07	0.97	0.99	0.93	0.96
Mn	0.10	0.10	0.10	0.10	0.06	0.06	0.06	0.06
Mg	0.78	0.80	0.78	0.78	0.90	0.91	0.93	0.93
Ca	0.04	0.04	0.02	0.02	0.04	0.03	0.03	0.02
Moles % End Members								
Wo	0	0	0	0	0	1.00	0	0
En	42.00	43.00	41.00	41.00	47.00	46.00	48.00	48.00
Fs	58.00	57.00	59.00	59.00	53.00	53.00	52.00	52.00

Table 2: Representative microprobe data of hornblende in the charnockitic gneiss											
Oxides (wt%)	**core**	**rim**	**core**	**rim**	**core**	**rim**	**core**	**rim**	**core**	**rim**	**core**
SiO_2	41.10	40.79	41.90	41.27	41.57	41.35	40.84	40.53	41.64	41.01	41.31
TiO_2	1.52	1.09	1.27	1.33	1.45	1.43	1.52	1.08	1.26	1.24	1.27
Al_2O_3	10.89	11.37	10.80	12.20	11.20	11.12	10.74	11.21	10.65	12.03	10.87
FeO	21.60	21.84	21.16	21.63	21.25	21.73	21.60	21.83	21.16	21.62	21.24
MnO	0.56	b0.55	0.63	0.54	0.55	0.52	0.55	0.55	0.63	0.54	0.55
MgO	8.17	7.80	8.42	8.00	8.37	8.33	8.02	7.66	8.27	7.85	8.22
CaO	10.91	11.19	11.08	11.42	11.02	11.21	10.95	11.23	11.12	11.46	11.10
Na_2O	1.57	1.32	1.52	1.33	1.45	1.43	1.60	1.34	1.54	1.34	1.47
K_2O	1.42	1.66	1.31	1.70	1.46	1.50	1.41	1.65	1.30	1.70	1.46
Sum	97.74	97.61	98.09	99.42	98.14	98.62	97.23	97.08	97.57	98.79	97.49
Cations calculated on the basis of 23 oxygens											
Si	6.23	6.21	6.31	6.16	6.25	6.21	6.23	6.22	6.23	6.17	6.25
Al (iv)	1.77	1.79	1.69	1.84	1.75	1.79	1.76	1.78	1.72	1.82	1.75
Al (vi)	0.17	0.25	0.22	0.30	0.21	0.18	0.17	0.24	0.17	0.30	0.19
Ti	0.17	0.13	0.14	0.15	0.16	0.16	0.17	0.12	0.14	0.14	0.14
Fe^{3+}	0.98	0.93	0.92	0.88	0.95	0.98	0.91	0.71	0.89	0.82	0.90
Fe^{2+}	1.76	1.90	1.75	1.82	1.73	1.75	1.84	2.08	1.77	1.90	1.84
Mn	0.10	0.10	0.10	0.10	0.07	0.07	0.10	0.10	0.10	0.10	0.10
Mg	1.85	1.77	1.89	1.78	1.88	1.86	1.82	1.75	1.86	1.76	1.84
Ca	1.77	1.83	1.79	1.83	1.78	1.80	1.79	1.84	1.80	1.84	1.82
Na	0.46	0.39	0.44	0.38	0.42	0.42	0.47	0.54	0.45	0.40	0.42
K	0.27	0.32	0.25	0.32	0.28	0.29	0.27	0.32	0.25	0.32	0.28

4.2.3 Biotite

The micro-chemical composition of biotite is given in Table 3. SiO_2: 35.68 – 36.21%; FeO: 20.72 – 21.93%; MgO: 10.76 – 11.38%; Al_2O_3: 14.55 – 14.93%; TiO_2: 3.60 – 5.21%; CaO: 0.02 – 0.06 and K_2O: 9.46 – 9.76% for both core and rim compositions. The recalculated formula showed that the biotite is siderophyllite.

4.2.4 Plagioclase feldspar

The chemical composition of plagioclase feldspar is presented in Table 4. SiO: 56.80 – 58.57%; Al_2O_3: 25.17 – 27.21%; CaO: 6.91 – 8.50%; Na_2O: 6.55 – 7.40% and K_2O: 0.21 – 0.41% for core and compositions. In terms of end members, average composition is given as $An_{35}Ab_{62}$ and $An_{38}Ab_{60}$ for core and rim compositions respectively.

4.2.5 Alkali Feldspar

The chemical composition of alkali feldspar in the charnockitic gneiss presented in Table 5. SiO: 62.70 – 64.61%; Al_2O_3: 18.44 – 18.95%; K_2O: 14.10 – 14.98%; Na_2O: 1.02 – 1.67% and CaO: 0.02 – 0.04 for core and rim compositions. Average compositional range expressed as $Or_{88}Ab_{12}Wo_0$ indicate microcline.

Table 3: Representative microprobe data of biotite in the charnockitic gneiss								
Oxides (wt%)	**core**	**rim**	**core**	**rim**	**core**	**rim**	**core**	**rim**
SiO_2	35.87	35.93	35.99	36.14	36.21	35.96	35.9	35.68
TiO_2	4.71	4.73	3.96	4.11	5.21	5.04	4.42	3.6
Al_2O_3	14.56	14.93	14.86	14.55	14.67	14.77	14.73	14.78
FeO	20.9	21.24	21.44	21.27	20.72	20.77	21.93	20.76
MnO	0.19	0.23	0.21	0.21	0.28	0.27	0.22	0.2
MgO	10.94	10.91	11.33	11.1	10.76	10.98	11.11	11.38
CaO	0.04	0.06	-	0.02	0.04	0.04	-	0.06
NaO	0.05	0.08	0.01	0.03	0.08	0.06	0.04	-
K_2O	9.46	9.58	9.76	9.73	9.7	9.61	9.71	9.66
Sum	**96.72**	**97.69**	**97.56**	**97.16**	**97.58**	**97.5**	**98.06**	**96.12**
Cations on the basis of 4 cations, 6 oxygens								
Si	5.4	5.36	5.38	5.42	5.4	5.37	5.36	5.4
Al (iv)	2.58	2.62	2.61	2.51	2.57	2.6	2.6	2.6
Al (vi)	-	-	-	-	-	-	-	-
Ti	0.53	0.53	0.44	0.46	0.57	0.56	0.5	0.45
Fe^{2+}	2.63	2.65	2.68	2.67	2.58	2.6	2.74	2.62
Mn	0.02	0.03	0.02	0.02	0.03	0.03	0.03	0.02
Mg	2.45	2.42	2.53	2.48	2.4	2.44	2.47	2.56
Ca	-	0.01	-	-	-	-	-	0.01
Na	0.01	0.02	-	0.01	0.02	0.01	0.01	-
K	1.81	1.82	1.86	1.86	1.84	1.83	1.85	1.86
Fe^{2+}/Fe^{2+}+Mg	0.51	0.52	0.51	0.51	0.52	0.51	0.52	0.5

Table 4: Representative microprobe data of plagioclase feldspar in charnockitic gneiss											
Oxides (wt%)	**core**	**rim**	**core**	**rim**	**core**	**core**	**rim**	**core**	**rim**	**core**	**rim**
SiO	58.19	58.57	57.93	57.87	57.88	58.17	57.37	57.37	56.8	57.78	57.25
TiO	-	0.08	0.03	0.01	0.07	-	-	-	-	-	-
Al	25.38	25.68	25.17	25.75	25.66	25.92	27.21	26.4	27.24	26.63	26.72
FeO	0.07	0.53	0.07	0.13	0.07	0.1	0.36	0.05	0.02	0.07	0.11
MgO	-	-	-	-	-	-	-	-	-	-	-
MnO	-	0.01	-	0.02	-	0.1	-	-	-	0.01	0.11
CaO	7.05	7.14	6.91	7.27	7.16	7.36	8.4	7.53	8.5	7.76	7.92
Na	7.08	7.15	7.4	7	7.15	7.08	6.81	7.12	6.55	6.81	6.78
K	0.4	0.21	0.31	0.22	0.29	0.41	0.23	0.41	0.21	0.4	0.35
Sum	**98.17**	**99.3**	**97.82**	**98.27**	**98.28**	**99.14**	**100.38**	**98.88**	**99.32**	**99.13**	**99.24**
Structural formula recalculated based on 8 oxygens											
Si	2.68	2.63	2.64	2.63	2.63	2.62	2.56	2.6	2.56	2.6	2.58
Ti	-	-	-	-	-	-	-	-	-	-	-
Al	1.36	1.36	1.35	1.37	1.37	1.38	1.43	1.4	1.44	1.41	1.02
Fe^{3+}	-	-	-	-	-	-	0.01	-	-	-	-
Mn	-	-	-	-	-	-	-	-	-	-	-
Mg	-	-	-	-	-	-	-	-	-	-	-
Ca	0.34	0.34	0.33	0.35	0.35	0.35	0.4	0.36	0.41	0.37	0.38
Na	0.62	0.62	0.65	0.61	0.63	0.62	0.6	0.62	0.57	0.6	0.6
K	0.02	0.01	0.01	0.01	0.01	0.02	0.01	0.02	0.01	0.02	0.02
Moles % End Members											
An	34.7	35.1	33.5	36	35	35.6	40	36	41.3	37.8	38.4
Ab	63	63.6	64.8	62.7	63.3	62	58.7	61.7	57.5	60	59.5
Or	2.3	1.3	1.7	1.3	1.7	2.4	1.3	2.3	1.2	1.2	2.1

Table 5: Representative microprobe data of alkali feldspar in the charnockitic gneiss										
Oxides (wt%)	**core**	**rim**	**core**	**rim**	**core**	**rim**	**core**	**rim**	**core**	**rim**
SiO_2	62.70	62.72	64.28	64.31	64.61	63.63	63.73	63.58	63.60	64.01
TiO	-	0.01	0.01	0.01	0.04	-	0.01	0.01	0.02	0.02
Al_2O_3	18.70	18.95	18.44	18.68	18.78	18.91	18.86	18.95	18.79	18.81
FeO	0.04	-	0.04	-	0.03	0.02	0.01	-	-	-
MnO	-	-	-	-	0.02	-	-	-	-	-
MgO	-	-	-	-	0.01	-	-	-	-	-
CaO	0.03	0.04	0.03	0.04	0.04	0.03	0.04	0.02	-	-
Na_2O	1.43	1.02	1.14	1.04	1.41	1.27	1.67	1.14	1.19	1.15
K_2O	14.97	14.98	14.98	14.98	14.48	14.71	14.10	14.97	14.56	14.67
Sum	**97.57**	**97.72**	**99.06**	**99.24**	**99.42**	**98.57**	**98.42**	**98.68**	**98.16**	**98.66**
Structural formula recalculated based on 8 oxygens										
Si	2.96	2.95	2.99	2.98	2.98	2.97	2.96	2.96	2.97	2.98
Ti	-	-								
Al	1.04	1.05	1.01	1.02	1.02	1.04	1.03	1.04	1.03	1.03
Na	0.10	0.10	0.10	0.09	0.12	0.11	0.15	0.10	0.10	0.10
K	0.90	0.90	0.89	0.88	0.85	0.87	0.87	0.89	0.87	0.87
Moles % End Members										
An	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	-	-
Ab	10.2	9.4	10.4	9.5	12.9	11.6	14.7	10.4	11.1	10.7
Or	89.6	90.4	89.4	90.3	86.9	88.2	85.1	89.5	88.9	89.3

4.3 Major Element Geochemistry

The average composition of the major oxides is presented in Table 6. SiO_2 (62 wt%); TiO_2 (0.45 wt%); Al_2O_3 (14,15 wt%); FeO_t (8.18 wt%); MgO (2.71 wt%); MnO (0.08 wt%); CaO (4.05 wt%); Na_2O (3.07 wt%); K_2O (2.26 wt%), P_2O_5 (0.16 wt%) and LOI (0.78 wt%).

4.4 Trace Elemental Composition

The average composition of the compatible elements such as Zn (71.2 ppm); Cr (96.5 ppm) are shown in Table 6. Immobile transition element such as Nickel (Ni) has average composition of 38 ppm. For the compatible elements such as Barium (Ba), Strontium (Sr) and Rubidium (Rb) have average compositions of 535 ppm, 371.7ppm and 81.8 ppm respectively.

4.5 Rare Earth Element Geochemistry

All samples showed enrichment in light rare earth elements (LREE) and depletion in the heavy rare earth elements (HREE) with negative europium (Eu) anomaly. Eu/Eu^* ranged from 0.44 to 0.89 with an average of 0.61 (Table 6).

Table 6: Major oxides (wt%), trace and rare earth elements (ppm) composition of charnockitic gneiss of Ikeram area								
Sample No Oxides (wt%)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Average**
SiO_2	67.1	61.5	65.3	66.3	66.1	65.0	64.0	65.0
TiO_2	0.5	0.6	0.5	0.4	0.7	0.5	0.6	0.45
Al_2O_3	13.40	15.20	13.5	13.1	15.9	14.5	13.50	14.15
FeO	8.08	8.11	7.95	8.73	11.23	5.12	8.08	8.18
MnO	0.08	0.09	0.08	0.10	0.13	0.08	0.06	0.08
MgO	1.94	2.88	2.19	1.30	4.09	3.80	2.80	2.71
CaO	3.34	4.65	2.95	3.51	5.82	4.50	3.63	4.05
Na_2O	3.14	3.66	2.75	2.68	3.00	2.65	3.65	3.07
K_2O	1.37	1.94	3.45	2.68	1.45	2.58	2.35	2.26
P_2O_5	0.07	0.20	0.13	0.18	0.26	0.17	0.13	0.16
LOI	0,72	0.77	0.85	0.77	0.92	0.72	0.72	0.78
Total	99.73	99.68	99.67	99.70	99.64	99.63	99.68	99.67
Trace Elemets(ppm)								
Ba	448	464	607	656	466	465	645	535
Cr Ga	99 16	72 22	81 18	61 17	179 18	64 17	84 16	91.4 17.7
Nb Ni	< 10 42	<10 43	11 42	11 19	< 10 44	11 42	<10 40	5.5 38
Rb	50	69	113	97	78	68	98	81.8
Sr	394	567	253	297	349	394	348	371.7
V	93	108	93	65	142	107	68	96.5
Y	<10	20	18	35	23	18	< 10	23.4

Table 6 (Cont): Major oxides (wt%), trace and rare earth elements (ppm) composition of charnockitic gneiss of Ikeram area

Sample No Oxides (wt%)	1	2	3	4	5	6	7	Average
Zn	72	83	58	62	97	57	70	71.2
Zr	135	180	186	250	134	184	180	178.4
K_2O/Na_2O	0.43	0.53	1.23	1.00	0.48	0.50	1.00	0.73
K/Rb	227.4	233.4	235	229.3	154.3	228.2	229.2	219.5
Ba/Rb	8.96	6.72	5.37	6.76	5.87	6.83	6.17	6.65
Ba/Sr	1.13	0.81	2.40	2,2	1.33	1.18	1.73	1.54
Sr/Y	ND	28.3	14	8.48	15,1	21.8	ND	17.5
Rb/Sr	1.13	0.12	0,46	0.32	0.22	0.17	0.28	
ASI	1.0	0.90	1.0	1.0	1.0	1.0	1.0	0.78
REE (ppm)								
La	45	38	40	49	80	70	46	46
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	1.4
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	1.3
Er	5.7	1 .7	3.6	4.6	5.9	4.5	5.8	4.5
Tm	0.17	0.18	0.51	0.65	0.85	0.18	0.62	0.45
Yb	5.6	1.6	3.6	4.4	5.8	5.5	3.8	4.3
Lu	0.60	0.24	0.59	0.66	0.89	0.47	0.25	0.52
∑REE	210.1	185.3	203.1	238.6	357.6	309.4	224.7	247
La/Yb_N	5.46	16.14	7.54	7.56	9.37	8.64	8.92	9.09
Eu/Eu*	0.62	0.65	0.89	0.44	0.46	0.72	0.54	0.61

4. Discussion

Mineral composition of the orthopyroxene analysed for in the charnockitic gneiss of Ikeram – Ibaram is hypersthene. The mineral is found closely associated with amphibole and plagioclase. Further analysis showed that the pyroxene is rich in iron (Fe) and therefore, can be regarded as Ferro-hypersthene. Orthopyroxene is an important component of charnockitic rocks in granulite facies terrains of the world. The CaO content in the ferro-hypersthene analysed is very low. It ranged from 0.48 to 1.22%. Ca atoms per formular does not exceed 1.0 which only occurs in M2 site (Cameron et al., 1981). Similarly, the alumina (Al_2O_3) content is low (< 1.0%) which is suggestive of low-pressure conditions. These are typical of granulite facies pyroxene composition. Oyawoye (1964) attributed formation of charnockite as a result of transformation of biotite, due to influx of iron-rich juvenile fluid. There are other ways by which orthopyroxene could be formed by mineral reactions.

Hornblende + Quartz Clinopyroxene + Orthopyroxene + Plagioclase + K-Feldspar + H_2O (1)

Biotite + Quartz ----------Orthoyroxene + K-Feldspar + H_2O (2)

These reactions are indicative of dehydration process due to low water activity (Perchuk et al., 1993). Mineral assemblage shows two generations of biotite and in case have close association with K-Feldspar (Figure 3). Also, biotite relicts in orthopyroxene grain show such dehydration process in the charnockitic gneiss of Ikeram – Ibaram (Figure 4). Dehydration of high-grade rocks in transition zones of amphibolite facies to granulite facies involve partial melting and in cases fluid solid state transformation (Harlov et al., 2006a; Harlov, 2012; Rigby et al., 2011). Corona texture observed where orthopyroxene (ferro-hypersthene) is mantled by amphibole (hornblende) is an indication of retrograde metamorphic event (Figure 5). This retrogression on the charnockite could be as a result of dehydration processes (Cameron et al., 1981). Retrogression involving breakdown of orthopyroxene is not uncommon in granulite terrains (Lasnier, 1977; Srikantappa et al., 1988). Orthopyroxene replaced by amphibole has been described in the granulite facies charnockitic gneiss of Iboropa Akoko, southwestern Nigeria (Ozeigbe, 2020). In this study, pyroxene viewed from back scattered electron image (BSE) has numerous cracks which could have aided movement of fluids (Figure 5). Relicts of biotite in orthopyroxene is also an indication of retrogression (Figure 4). Amphibole mantling othopyroxene could have developed in a process in which orthopyroxene reacts with plagioclase and quartz in presence of water. This can be expressed in this equation;

Orthopyroxene + $Plagioclase^1$ + Quartz + H_2O = Amphibole + $Plagioclase^2$ (1)

Similarly, biotite breakdown to form orthopyroxene can be represented by the equation (2)

Biotite + Quartz = Orthopyroxene + K- Feldspar + H_2O (2)

Equation (2) has been written as if they as if they occur in solid state, but quartz, K-Feldspar and water may occur as components in the melt rather than as solid phases (Frost et al., 2008). The biotite is siderophyllite as presented by the mineral chemistry (Table 3). Hornblende and biotite in charnockites have been found to be product of retrograde metamorphism involving pyroxene granulite facies rocks (Cooray, 1961; Cooray, 1962). Hornblende has higher values of magnesium when compared with those of co-existing orthopyroxene but has relatively higher TiO_2 composition (< 1.0%). Researchers linked this to increase in grade of metamorphism (Raase, 1974; Spear, 1981). TiO_2 content is higher in biotite than those of amphibole and orthopyroxene (average: 4.57 for core composition). Higher TiO_2 in biotite had been attributed to increase in stability field of biotite (Dymek, 1983). MgO compositions in hornblende (7.66 -8.42%) are far less to those of orthopyroxene (13.18 – 16.07%) but a bit close to biotite composition (10.76 – 11.38). Plagioclase is dominant feldspar with average composition given as $An_{35}Ab_{62}$ indicating andesine. The K-feldspar (microcline – orthoclase) has microperthitic texture which is common in high grade metamorphic terrains due to extreme high temperature (Cayzer, 2002). For the trace element composition, there is enrichment in Ba, Sr, Zr, but depletion in Rb. Rollinson and Tarney opined that Rb depletion in TTGs predates metamorphism of granulite facies

(Rollinson and Tarney, 2005). Ratios of Rb/Sr are low, while Ba/Rb are high for all samples of Ikeram-Ibaram charnockitic gneisses. REE patterns indicate LREE enrichment and HREE depletion with negative europium (Eu) anomaly. La/Yb_N ratios are above 5.0 suggesting evolution of the rocks through magmatic differentiation processes (Feng and Kerich, 1990). REE patterns obtained from study is similar to the works of Ozeigbe on retrogression of orthopyroxene-bearing gneiss of Iboropa Akoko and Olarewaju on charnockitic rocks of Ado-Ekiti area of Ondo State, southwestern Nigeria (Ozeigbe, 2020; Iboropa Akoko and Olarewaju, 1988).

5. Conclusion

Based on the petrographic evidences and mineral paragenes suggest a retrograde metamorphic event. Biotite relicts in orthopyroxene grains and mantling of orthopyroxene by amphibole are clear evidences of retrograde mineral reactions due to dehydration processes. Numerous microfractures observed in biotite and orthopyroxene grains could have aided migration of fluids that triggered the alterations seen in them. Trace element and Rare earth element (REE) compositions suggest continental behavior and the charnockitic gneiss of Ikeram-Ibaram could have evolved through magmatic differentiation processes.

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References

Cameron, M., Papike, J.J., 1981. Structural and chemical variations in pyroxenes. American Mineralogist, 66 (1-2), Pp. 1 – 50.

Cayzer, N., 1969. Metamorphic Textures. Pergamon Press, Oxford, England, Pp. 358.

Cooray, P.G., 1961. The Geology of the area around Rangala. Ceylon Geological Survey Memoir, 2, Pp. 138.

Cooray, P.G., 1962. Charnockitex and their associated gneisses in Precambrian of Ceylon. The Quarterly Journal of Geological Survey of London, 118, pp. 239 – 273.

Dymek, R.F., 1983. Titanium, aluminium and interlayer cation substitutions in biotite from high grade gneisses, west Greenland. American Mineralogist, 68 (9-10), Pp. 880 – 899.

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.

Frost, B.R., Frost, C.D., 2008. On charnockites. Gondwana Research, 13, Pp. 30 – 44.

Harlov, D.E., 2012. The potential role of fluids during regional granulite facies dehydration in the lower crust. Geosciences Frontiers, 3, Pp. 813 – 827.

Harlov, D.E., Johansson, L., Van Den Kerkhof, A, Förster, H.J., 2006a. The role of advective fluid flow and diffusion during localized solid-state dehydration: Sondrum Stenhuggeriet Halmstad, S.W Sweden. Journal of Petrology, 47, Pp. 3 – 33.

Holland, T.H., 1900. The charnockite series, a group of Archean hypersthenic rocks in Pennisular India. Memoir of Geological Survey of India, 28, Pp. 192 – 249.

Iloeje, N.P., 1976. A new geography of Nigeria. Metricated Edition, Longman Press.

Lasnier, B., 1977. Persistance d'une serie granulitique au coeur du Massif central francois, Haut – Allier: les termes basiques ultrabasiques et carbonates. PhD Thesis, Universite de Nantes, laboratoire de petrologie et de mineralogie, Nantes, Pp. 351.

Le Maitre, R.W., 2002. Igneous Rocks: A classification and glossary of terms. Cambridge University Press, Cambridge, Pp. 256.

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

Oyawoye, M.O., 1964. The contact relationship of charnockite and granite gneiss at bauchi, Northern Nigeria: Geological magazine, 101, Pp. 138 – 144.

Ozeigbe, E.J., Olarewaju, V.O., Ocan, O.O., Costin, G., 2020. Retrogression of orthopyroxene-bearing gneiss of Iboropa Akoko, southwestern Nigeria. Materials and Geoenvironment. httpps://doi.org/10.2478/rmzmag.2020-0009.

Parras, K., 1958. On the charnockites in the light of a highly metamorphic rock complex in southwestern Finland. Bullentin Comm Geol. Finlande., Pp. 181.

Perchuk, L.L., Gerya, T.W., 1993. Fluid control of charnockitization. Chemical Geology, 108, Pp. 175 – 186.

Pichamuthu, C.S., 1960. Charnockite in the making. Nature, 188, Pp. 135 – 136.

Raase, P., 1974. Al and Ti contents of hornblende, indicators of pressure and temperature of regional metamorphism. Contributions to Mineralogy and Petrology, 45 (3), Pp. 231- 236.

Rahaman, M.A., Ocan, O.O., 1988. The nature of granulite facies metamorphism in Ikare area, southwestern Nigeria. In Precambrian Geology of Nigeria, edited by P. Oluyide, Pp. 157 – 163.

Rajesh, H.M., 2012. A geochemical perspective on charnockite magmatism in Peninsular India. Geoscience Frontiers, (6), Pp. 773 – 788.

Rigby, M.J., Droup, G.T.R., 2011. Fluid- absent melting versus CO_2 streaming during the formation of politic granulites: A review of insights from cordierite fluid monitors, origin and evolution of Precambrian high grde gneiss terranes with special emphasis on the Limpopo complex of South Africa, 207, Pp. 39.

Rollinson, H.R., Tarney, J., 2005. Adakites- A key to understanding LILE depletion in granulites. Lithos, 79, Pp. 61 – 81.

Spear, F.S., 1981. An experimental study of hornblende stability and variability in amphibolites. American Journal of Science, 281 (6), Pp. 697 – 734.

Srinkantappa, C., Prakash, C., Narasimha, K.N., 1988. Retrogression of charnockite in Moyar shear zone of Tamil Nadu. Journal of the Geological Society of India, 11, Pp. 117 – 124.

Yamg, Q.Y., Santosha, M., Tsunogae, T., 2014. First report of Paleoproterozoic incipient charnockite from the North China Craton: Implications for ultra-high temperature metasomatism. Precambrian Research, 243, Pp. 168 – 180.