Discovery Nature

Mineral chemistry and P-T conditions of incipient Charnockite around Ikare, Southwestern Nigeria

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To Cite:
Oyeshomo AV, Bolarinwa AT, Altenberger U, Harlov DE, Olayemi SO, Ajila TF. Mineral chemistry and P -T conditions of incipient Charnockite around Ikare, Southwestern Nigeria. *Discovery Nature* 2025; 2: e1dn1039
doi: https://doi.org/10.54905/disssi.v2i3.e1dn1039

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Peer-Review History
Received: 07 September 2024
Reviewed & Revised: 11/September/2024 to 16/December/2024
Accepted: 19 December 2024
Published: 03 January 2025

Peer-Review Model
External peer-review was done through double-blind method.

Discovery Nature
pISSN 2319-5703; eISSN 2319-5711

DISCOVERY SCIENTIFIC SOCIETY

ABSTRACT

Charnockites could be of magmatic, metamorphic, or metasomatic origin and formed in diverse geotectonic settings. Previous works on incipient charnockitic rocks outcropping around Ikare, southwestern Nigeria, were inconclusive due to lack of micro-chemical data for pressure-temperature estimation. Hence, this present study was designed to determine the petrology, geochemistry, and pressure-temperature estimates of these charnockitic rocks. Petrographic studies showed that the essential minerals are quartz, plagioclase, alkali feldspar, biotite, orthopyroxene and hornblende ± clinopyroxene. The accessory minerals are zircon, apatite, ilmenite, and magnetite. Hornblende is stable with orthopyroxene. Plagioclase feldspars in the charnockite are andesine and be expressed as An35Ab64. Orthopyroxene be described as Fs57.5En42.5Wo0 are mainly hypersthene. Hornblende in the incipient charnockite varies from pargasite to ferropargasite in composition. Alkali feldspar is a microcline. Geothermobarometric computations using both hornblende-plagioclase and two-feldspar thermometers obtained temperatures ranging from 7400C to 8000C at assumed pressure of five kbar. The temperature range 8000C recorded on thermodynamic modeling of a sample, further suggest a low pressure-high temperature metamorphic conditions for the incipient charnockite around Ikare

Keywords: Magmatic, micro-chemical, geothermobarometric, incipient charnockite, Ikare

1. INTRODUCTION

Pichamuthu, (1960) introduced the term "incipient charnockite", which denote the or thopyroxene ± garnet - bearing dark greenish metamorphic rock of dehydration zones. This rock is alike in look with similar mineral assemblage to the charnockite at the type region in southern India earlier described by (Holland, 1900). Such restricted dehydration zones occurred over an area of centimetres to a few metres in the host grey gneisses. Pichamuthu, (1960) observed these charnockitic patches within the gneisses in south India and suggested that they were formed probably through infiltration of fluid rich in CO2. Most fluid inclusion studies from different authors showed infiltration of CO2 - rich inclusions and they concluded that these charnockites in southern India are of metamorphic origin where the host gneisses were dehydrated through invasion by carbonic rich fluid released from underplated basalts or carbonates.

Pichamuthu, (1960) and Perchuk and Gerya, (1993) proposal on charnockitization was supported by the phase modeling introduced by (Endo et al., 2012; Newton et al., 1980; Hansen et al., 1995). Harlov, (2012) considered infiltration by invading fluid, preferably of low a-H2O during granulite metamorphism may trigger the dehydration of the host gneisses. Some authors suggest a deficient process in the dehydration of the lower crust to preserve orthopyroxene instead of biotite or hornblende breakdown in the charnockites petrogenesis (Srikantappa et al., 1985; Burton and O'Nions, 1990; Rimsa, 2007). Srikantappa and Kumar, (1987) proposed progressive charnockitization, while Bhattacharya and Sen, (2000) contend the relation in grain size between minor patches and neighboring bigger bodies does not support the hypotheses.

Howie, (1954) suggestted the theory of plutonic metamorphism of large extent charnockitic rocks in many granulite terranes. Rao and Rao, (1988) described the intrusive origin of charnockitic rocks from Eastern Ghats and recognized two groupings, specifically charnockite and basic granulite. Similar charnockitic patches in host gneisses appear in Ikare, southwestern Nigeria. Rahaman and Ocan, (1988) studied these patches and noted that they occur in the transition zone of amphibolites facies to granulite facies metamorphism in Ikare area, but reiterated that their study was limited to petrography and not geochemistry. Works of Oziegbe et al., (2020) and Oyawale and Ocan, (2020) did not apply a geochemical approach to unravel the pressure - temperature conditions of these charnockitic patches, hence this present study intends to have a better understanding of these patches from the petrographic and geochemical views.

The study area, Ikare and its environ is situated in the northernmost part of Ondo State, Nigeria and lies between latitudes 70 30'- 70 45'N and longitudes 50 45'- 60 00'E (Figure 1). It is essentially underlain by rocks of southwestern basement rocks. The gneissic rocks (grey and granite) are the most predominant rock types and are intruded by charnockite and granite with pockets of hornblende - biotite gneiss, pelitic gneiss and, quartzite. This type of charnockitic body appear as patches in host grey gneiss around Victory college, Ikare on a small scale. The rock is generally light coloured, but punctuated by dark brownish grains of orthopyroxene present in them.

2. MATERIALS AND METHODS

Three representative samples (weighing 4 grams each) of the charnockite patches were collected with the aid of a sledgehammer wrapped and well labeled during fieldwork. The rocks were then cut into thin and polished sections for the petrographic observation. The rocks were also grinded and crushed into geochemical powder using jaw crushers at the workshop of the Department of Earth Sciences, Adekunle Ajasin University, Akungba - Akoko, Nigeria. The powders were further processed into glass pellets for geochemical analysis at the Institute of Earth and Environmental Science, University of Potsdam, Potsdam, Germany.

Micro-chemical analyses was carried out using electron microprobe analyser- JEOL JSM-6510 fitted with INCA-X-act. It housed at the Institute of Earth and Environmental Science, University of Potsdam, Golm-Potsdam, Germany. The instrument was operated at a voltage of acceleration of 15 KeV and also, at regulated beam current of 15 nA. The electron beams were of 1μm in size. A total of four minerals namely, plagioclase feldspar, orthopyroxene, alkali feldspar and hornblende of the charnockite patches were probed for their mineral chemistry to estimate the pressure-temperature conditions of the incipient charnockite around Ikare region.

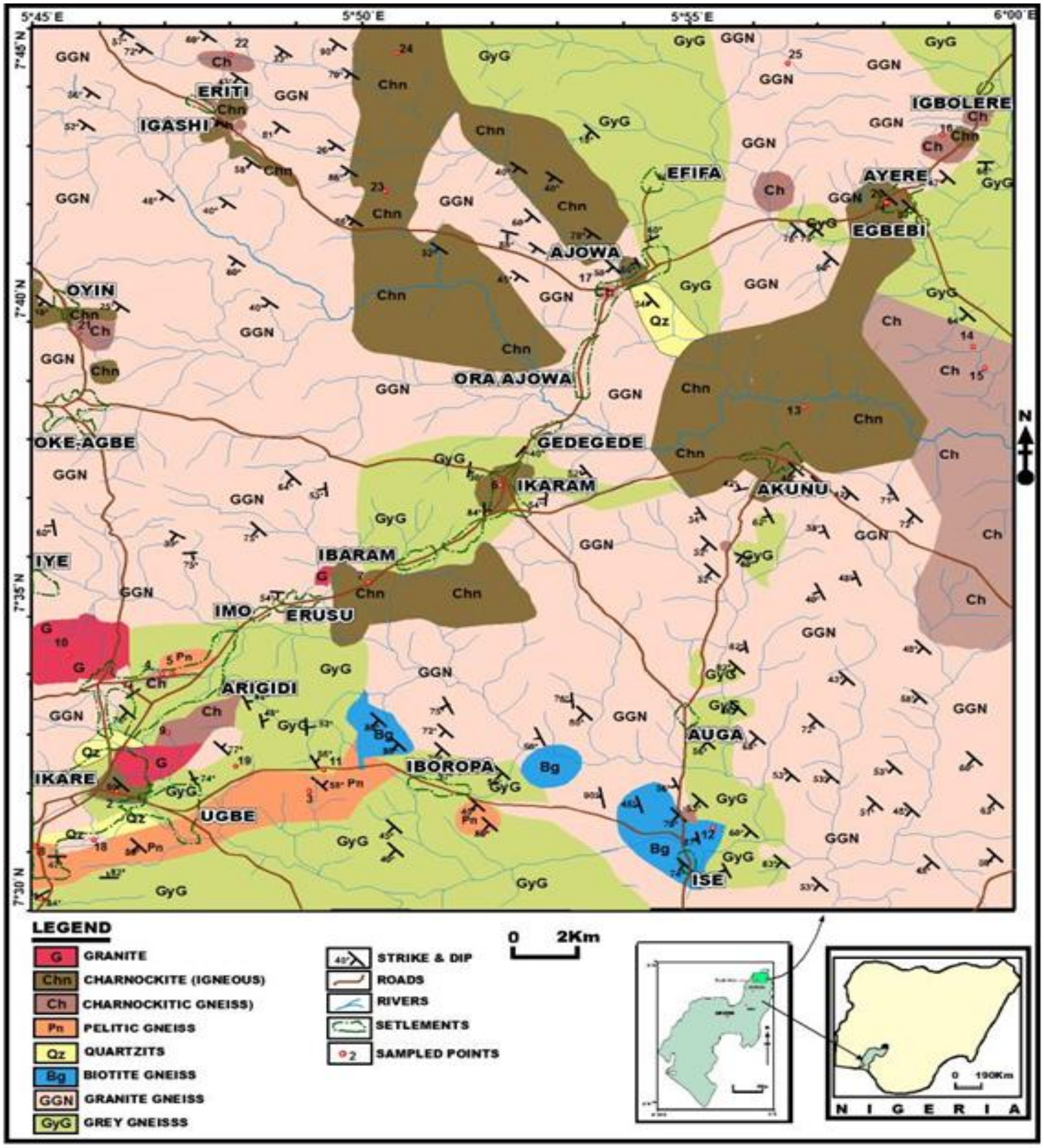

Figure 1 Geological map of Ikare and its environment (after Oyeshomo, 2023)

3. RESULTS

Petrography

The rock is coarse grained, and foliated. The foliation is marked by the prefeered orientation of long axes of biotite grains. In some cases, the grains of orthopyroxene are found cross-cutting the foliation in the rock and spots of orthopyroxene can be seen in the leucotome of the host gneiss (Figure 2). In thin sections, the mineral assemblages are biotite, hornblende, plagioclase, quartz, alkali feldspar (perthite), and orthopyroxene, while the accessory minerals are apatite, ilmenite and zircon. Quartz are seen to be anhedral in shape with wavy extinction, which is an indication of deformation after crystallization of the rock. Quartz occurs as inclusions inside feldspar and orthopyroxene grains. Plagioclase feldspars are anhedral in shape with pronounced albite/polysynthetic twinning with bent twin lamellae, indicating intense deformation. Both perthite and anti-perthite feldspars are present. Such ex-solution occurs as low temperature intergrowth.

Figure 2 Field photographs (a) clots of orthopyroxene grains in the host grey gneiss and (b) orthopyroxene in the leucotome of the grey gneiss near Victory College, Ikare

Under cross nicol, skeletal grains of orthopyroxene are seen in prefereed orientation surrounded by quartz, biotite and alkali feldspar (Figure 3). Biotite occurs in two forms under in the slides. One type is pale brown, while the other occur as greenish-brown in colouration. This possibly represents two generations of biotite grains as seen under cross nicol (Figure 4). There are myrmekite intergrowth at the margin of alkali feldspar with quartz and, biotite. The intergrowth is these rocks are said to be formed by the breakdown of the anorthite molecules in plagioclase (Ramaswamy and Murty, 1972). Bhattacharyya, (1971) considered it as a function of stress while, attributed their formation to potash metasomatism.

Mineral chemistry

Plagioclase feldspar

Prefeered spots on plagioclase feldspars were selected for their mineral chemistry and were probed at both their core and rim compositions. The cations was obtained on account of eight oxygens. The end members are given in moles (%). Outcomes of analyses of the electron micro-chemical probe on the plagioclase feldspar are shown in (Table 1). The results showed that the plagioclase feldspar have the average composition of An33Ab65 calculated for the core and An35Ab64 for the rim, thereby indicating more or less constant andesine compositions for the core and the rim of the plagioclase feldspars probed. On the diagram of An-Ab-Or after Barker, (1979), for the classification of granitic rocks according to their molecular normative, the plagioclase feldspar plot in the tonalite field, which is a reflection of the intermediate composition of the plagioclase (Figure 5a). On the Or-An-Ab ternary plot for feldspar composition in granitic rocks, they plot in andesine field (Figure 5b).

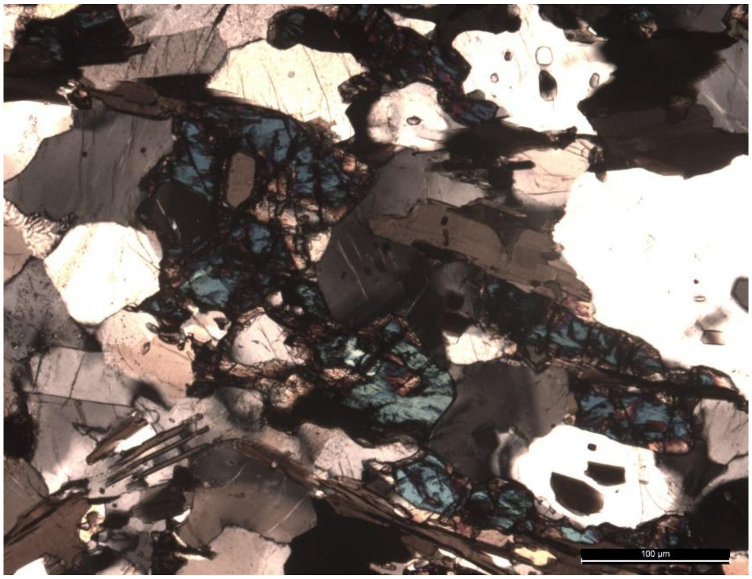

Figure 3 Otomicrograph showing skeletal grains of orthopyroxene in preferred orientation as seen under Cross Nicol.

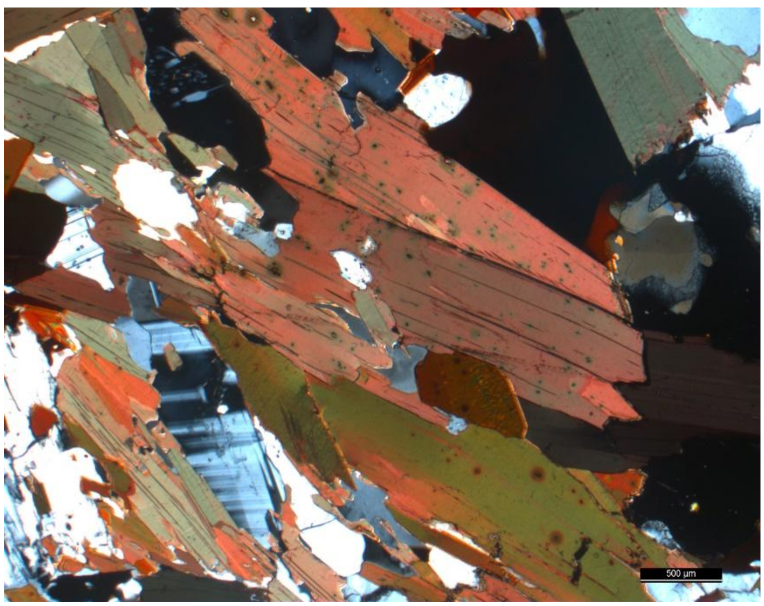

Figure 4 Photomicrograph showing two generations of biotite, pale brown and greenish brown types as seen under Cross Nicol.

Table 1 Representative microprobe data of plagioclase feldspar in the incipient charnockite of Ikare area.

Oxides (wt%) spots	Core	Rim	Core	Rim
SiO2	57.91	57.66	58.20	57.95
Al2O3	25.63	25.06	25.27	25.49
FeO	0.06	0.03	0.07	0.17
CaO	7.11	7.23	6.71	8.09
Na2O	7.34	7.06	7.50	6.98
K2O	0.38	0.21	0.30	0.50
Sum	99.33	97.25	98.05	99.18
Structural formula recalculated based on 8 oxygens				
Si4+	2.63	2.65	2.65	2.64
Al3+	-	1.36	1.36	1.37

Fe2+	-	-	-	0.01
Ca2+	0.35	0.36	0.33	0.34
Na+	0.46	0.63	0.66	0.66
K+	0.02	0.01	0.01	-
Moles % End Members				
An	3.43	3.57	32.6	34.0
Ab	64.1	63.1	66.0	66.0
Or	1.6	1.2	1.3	-

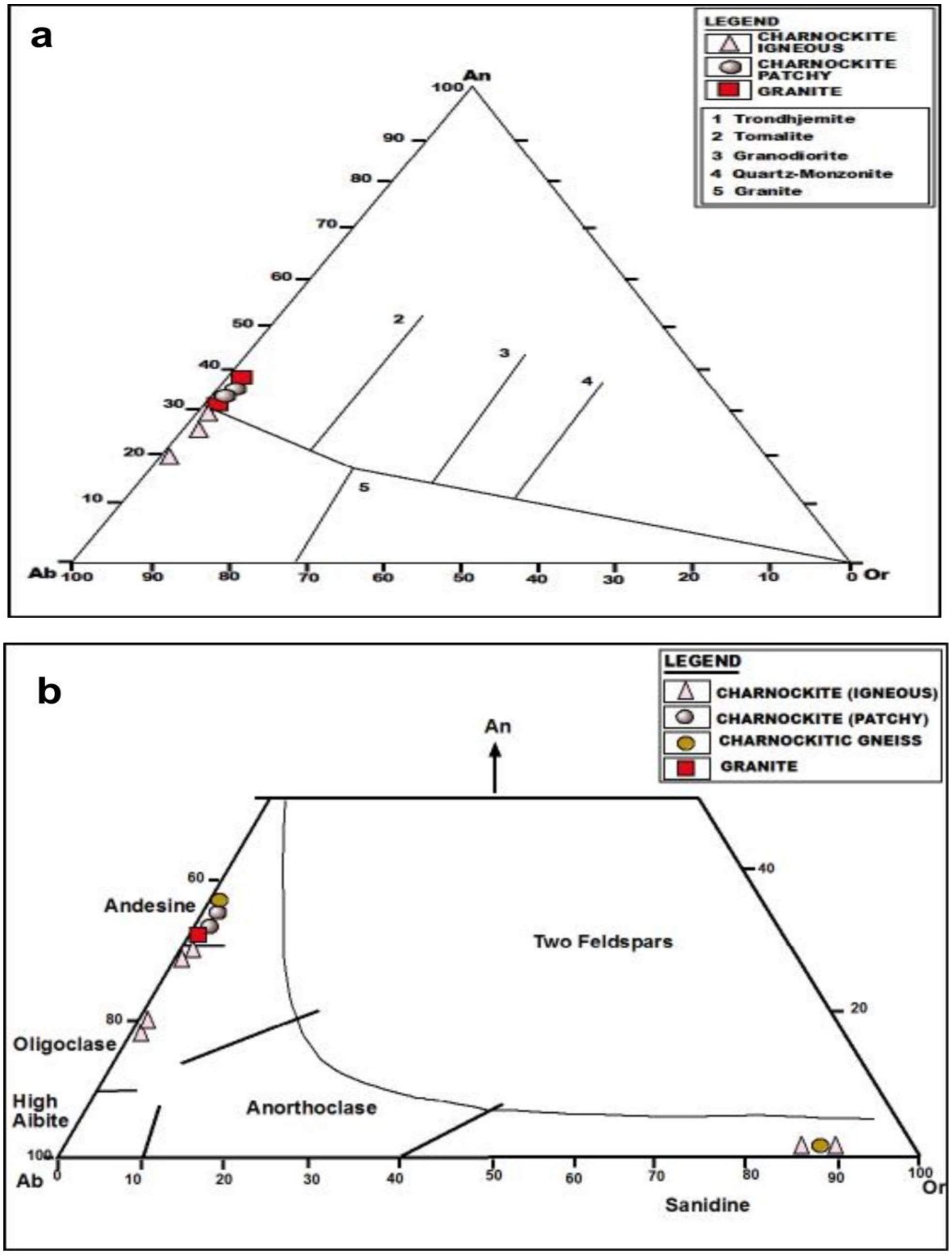

Figure 5 (a) Showing plagioclase feldspar from studied charnockite and associated rocks around Ikare, plot in the tonalite field (drawn after Barker, 1979) and (b) On the 2- feldspar diagram, the samples of charnockitic and associated rocks around Ikare, southwestern Nigeria, plot in the andesine field.

Orthopyroxene

Spots on orthopyroxene grains were chosen so as to determine their mineral chemistry. The cations were recalculcated on account of four cations and six oxygens. The end members are given in moles (%). Outcome are obtainable in (Table 2). The average compositional range of the orthopyroxene of the patchy charnockite can be described as Fs57.5En42.5Wo0 for the core and Fs58En42Wo0 for the rim compositions. On the Wo-En-Fs ternary diagram, the orthopyroxene plot in the hypersthene field (Figure 6).

Hornblende

Spots were selected on the hornblende grains for microprobe analysis so as to determine their mineral composition. The cations were recalculated on account of twenty three oxygens. The outcomes of the analysis are presented in (Table 3). To verify the nomenclature of amphiboles in patchy charnockite and associated rocks, a plot drawn after Leake et al., (1997) were carried out. From the plot, hornblende from the patchy charnockite and associated rocks range from pargasite to ferropargasite (Figure 7).

Alkali Feldspar

Three spots from alkali feldspar were selected for micro-chemical analyses. The cations were recalculated on the basis of eight oxygens. The outcomes of the analyses are shown in (Table 4). From the results, mole composition of orthoclase vary between 87.60% - 91.20% with average composition expressed as Or89Ab10An0.1 for core composition and those of the rim vary from 86.90% to 90.30% and expressed as Or88Ab11An0.2. On the of Or-Ab-An ternary plot for feldspar composition, the alkali feldspar plot in the microcline field (Figure 5b).

Table 2 Representative microprobe data of orthopyroxene in the incipient charnockite of Ikare area.

Spots	**Core**	**Rim**	**Core**	**Rim**	**Core**	**Rim**	**Core**	**Rim**
Oxide (wt%)								
SiO2	49.77	48.40	48.85	49.91	49.44	49.22	49.84	49.57
TiO2	0.06	0.02	0.01	0.03	0.05	0.01	0.05	0.03
Al2O3	0.70	0.50	0.42	0.55	0.53	0.53	0.53	0.50
FeO	34.94	34.56	35.93	36.28	35.60	35.20	35.38	34.71
MnO	1.61	0.91	1.54	1.71	1.75	1.56	1.65	1.56
MgO	14.07	14.43	13.55	12.92	13.63	13.46	13.91	13.98
CaO	0.65	1.18	0.58	0.55	0.64	0.64	0.52	0.47
Na	0.02	0.08	-	0.01	0.02	-	0.03	-
K2O	-	-	-	-	-	-	-	-
Sum	100.82	100.08	100.88	101.96	101.66	100.62	101.91	100.92
Structural formula recalculated based on 4 cations and 6 oxygens								
Si	1.95	1.83	1.93	1.93	1.93	1.94	1.93	1.94
Al (iv)	0.03	0.17	0.02	0.02	0.02	0.02	0.02	0.02
Mg	0.82	0.68	0.81	0.76	0.80	0.08	0.80	0.81
Fe2+	1.07	0.90	1.04	1.09	1.05	1.07	1.05	1.05
Ca	0.02	0.47	0.02	0.02	0.02	0.02	0.02	0.02
Moles (%) End Members								
Wo	0	0	0	0	0	0	0	0
En	43	42	43	40	42	41	42	42
Fs	57	58	57	60	58	59	58	58

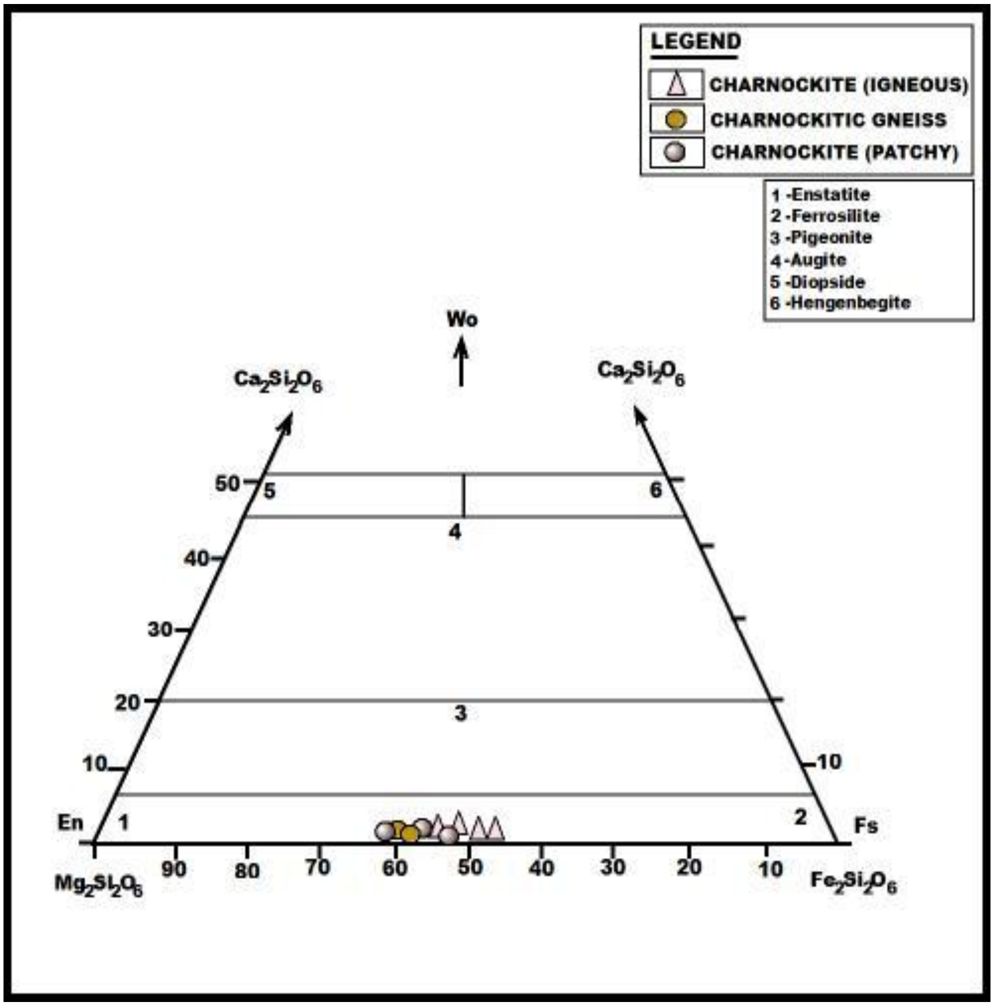

Figure 6 En-Fs-Wo diagram showing orthopyroxene from the incipient charnockite and associated rocks plot within the hypersthenes field.

Table 3 Representative microprobe data of hornblende in the incipient charnockite of the Ikare area.

Spots Oxides (wt%)	Core	Rim	Core	Rim	Core	Rim
SiO2	41.32	41.25	40.89	40.84	41.06	41.00
TiO	2.02	1.89	1.93	1.81	2.02	1.89
Al2 O3	11.88	11.25	11.24	11.20	11.22	11.10
FeO	21.61	21.19	21.28	21.43	21.60	21.19
MnO	0.37	0.37	0.37	0.36	0.37	0.37
MgO	8.09	8.24	7.90	7.84	7.94	8.09
CaO	11.08	11.20	11.24	11.20	11.22	11.10
Na2O	1.63	1.45	1.62	1.39	1.66	1.48
K2O	1.48	1.57	1.52	1.57	1.48	1.57
Sum	99.48	98.41	97.99	97.64	98.57	97.79
Structural formula recalculated based on 23 oxygens						
Si	6.20	6.22	6.23	6.22	6.21	6.20

Al(iv)	1.80	1.78	1.78	1.78	1.80	1.77
Al(vi)	0.21	0.22	0.24	0.24	0.20	0.21
Ti	0.23	0.21	0.22	0.21	0.23	0.22
Fe3+	0.82	0.79	0.65	0.76	0.73	0.78
Fe2+	1.89	1.88	2.05	1.97	2.01	1.91
Mn	0.05	0.05	0.05	0.05	0.05	0.05
Mg	1.81	1.85	1.79	1.78	1.79	1.83
Ca	1.78	1.81	1.83	1.83	1.82	1.82
Na	0.48	0.43	0.48	0.41	0.49	0.44
K	0.28	0.30	0.30	0.31	0.29	0.31

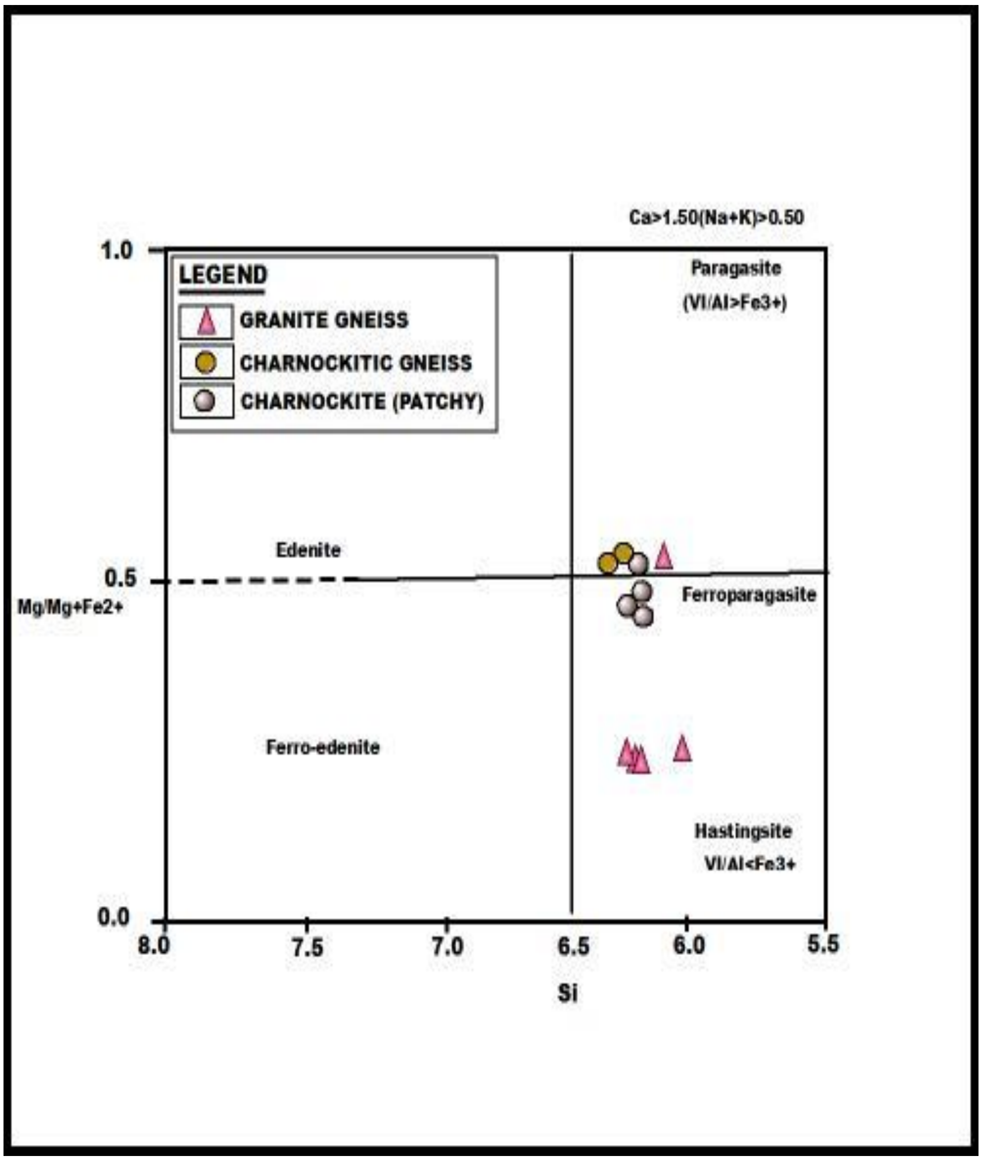

Figure 7 Showing the amphibole composition in the incipient charnockite and associated rocks of Ikare. Samples studied plot in ferropargasite field with the exception of one sample in pargasite field.

Table 4 Representative microprobe data of alkali feldspar in the incipient charnockite of Ikare area

Spots Oxides (wt %)	**Core**	**Rim**	**Core**	**Rim**	**Core**	**Rim**
SiO2	64.50	64.30	65.02	64.61	65.20	65.06
TiO2	0.01	0.01	0.00	0.04	0.00	0.00
Al2O3	18.40	18.64	18.50	18.70	18.87	18.75
FeOt	0.04	0.00	0.09	0.03	0.04	0.01
MnO	0.00	0.00	0.00	0.03	0.01	0.00
CaO	0.04	0.04	0.01	0.05	0.06	0.05
Na2O	1.15	1.04	0.96	1.40	1.35	1.28
K2O	14.97	14.98	15.37	14.48	14.74	14.56
Cations						
Si	2.99	2.99	3.00	2.97	2.98	2.97
Al (iv)	1.01	1.02	1.01	1.02	1.02	1.01
Fe	0.00	0.00	0.00	0.00	0.00	0.00
Ca	0.00	0.00	0.00	0.00	0.00	0.01
K	0.89	0.89	0.90	0.85	0.86	0.85
Sum	5.00	4.99	5.00	4.99	5.00	4.90
End Members						
An	0,20	0.20	0.00	0.20	0.30	0.30
Ab	10.40	9.50	8.80	12.90	12.10	11.80
Or	89.40	90.30	91.20	86.90	87.60	87.90

Geothermobarometry

The incipient (patchy) charnockites are composed of alkali feldspar (microcline-orthoclase), plagioclase feldspar (andesine), quartz (qtz), orthopyroxene (hypersthene), hornblende (pargasite-ferro-pargasite), magnetite (mt) and biotite (bt). The feldspars locally showed evidence of thin ex-solution lamellae. Hornblende is stable with orthopyroxene and not formed due to regression. In this study, plagioclase-hornblende thermometry and two-feldspar thermometry of Holland and Blundy, (1994) at pressure by Schmidt, (1992) together with Anderson and Smith, (1995) were chosen for the purpose of pressure-temperature estimation.

The two-feldspar thermometry gave temperatures of ca.740 ºC at five kbar, while hornblende-plagioclase thermometry recorded temperature around 8000C at five kbar (Table 4). Thermodynamic modeling using theTheriak-Domino software of De-Capitani and Petrakakis, (2010) gave temperatures of about 800 ºC assuming pressure of about five kbar (Figure 8). The two-Feldspar thermometry obtained in this study is similar to the work of Lee et al., (2021) on incipient charnockite of Yeongnan Massif, Korea, in which they obtained ranges of 770-8400C at three and half - to eight and half kbar.

4. DISCUSSION

The incipient charnockite or patchy charnockite outcropping around Ikare, southwestern Nigeria, occurs within amphibolite-granulite facies transition zone enclosed by high grade metamorphic rocks (grey and granite gneisses). These charnockitic patches in host grey gneisses had been reported in several parts of the world, notably Eastern Ghats, Kabbaldunga and Kerala districts of India. Notable occurrences of these patches were reported within the granulite facies rocks by (Subramanian, 1959; Howie, 1959; Cooray, 1979; Condie and Allen, 1984).

Table 4 Estimated pressure-temperature conditions for incipient charnokite around Ikare, southwestern Nigeria.

Rock Type	Hbl - Pl Thermometry	2 - Feldspar Thermometry
Incipient charnockite around Victory College, Ikare, S.W Nigeria	c - 8000C r - 7860C @ five kbar HB, (1994)	7400C @ five kbar

c - core, and r - rim, Hbl - Hornblende, Pl – Plagioclase, HB - Holland and Blundy

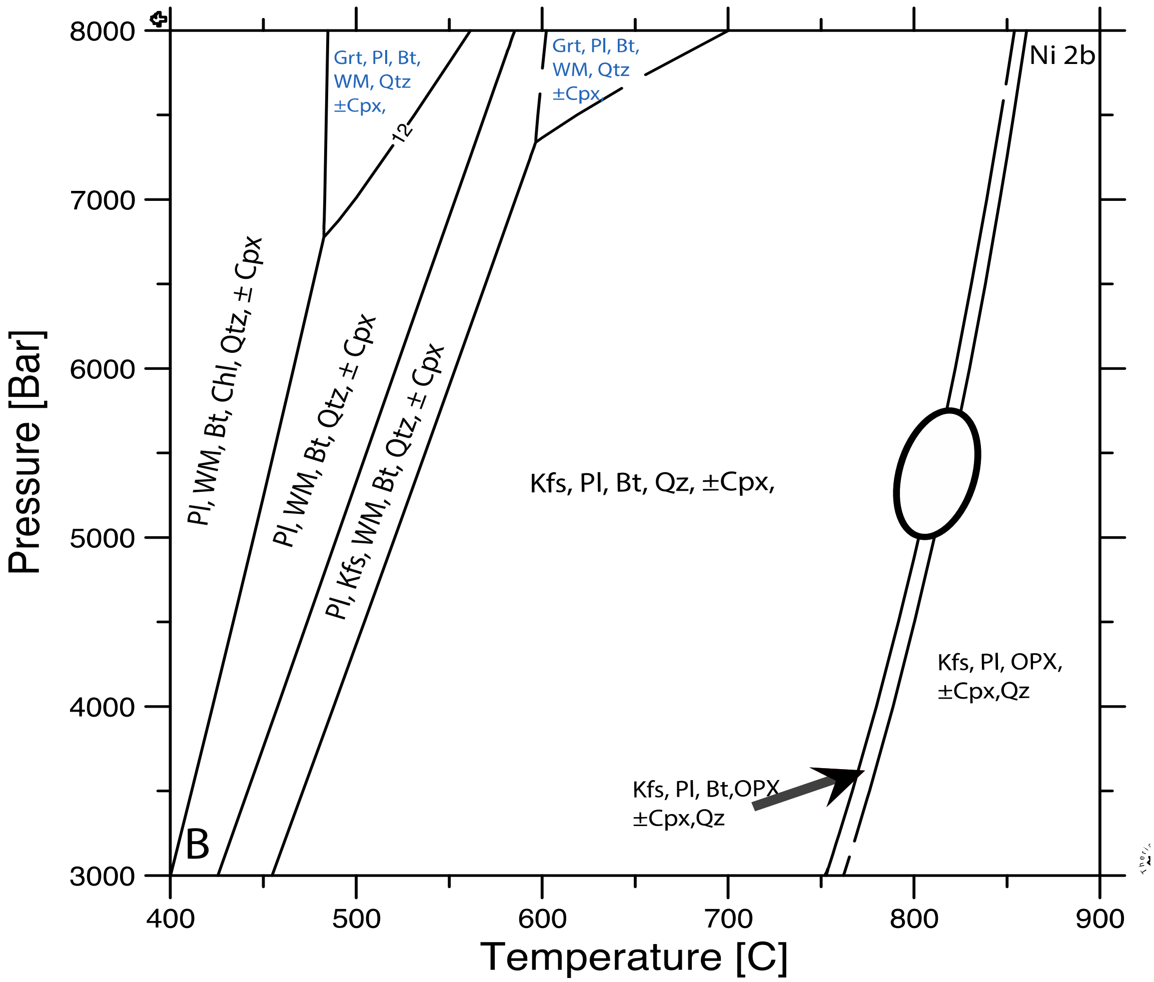

Figure 8 Thermodynamic modeling of patchy charnockite in host grey gneiss around Ikare Akoko, southwestern Nigeria (drawn after De-Capitani and Petrakakis, 2010).

They contain similar mineral assemblage like their host gneisses except, for the pyroxene (hypersthene). Typical mineral assemblages are quartz, plagioclase, orthopyroxene, biotite, alkali feldspar and hornblende ± clinopyroxene. The accessory minerals are ilmenite, apatite, magnetite and, zircon. Micro-chemical analysis showed that orthopyroxene is hypersthene in composition, plagioclase (andesine), alkali feldspar (microcline), hornblende (ferro - pargasite). The pyroxene has substantial amount of iron typical of granulite facies composition. Petrographic evidence showed that the texture is granoblastic due to brownish grains of orthopyroxene obliterating foliation in the host grey gneiss. Two generations of biotite occurs in the rock. One is pale brown in coloration, while the other is dark brown which suggests that they are of different origin. Myrmekite intergrowths are common.

Hornblende is stable with orthopyroxene and this foreclosed retrogression. Using two-Feldspar thermometry and Hornblende - Plagioclase of Holland and Blundy, (1994) gave a temperature range of 740 - 8000C for both core and rim at five kbar. This is in agreement with 8000C obtained from thermodynamic modeling on a sample of charnockitic patches (drawn after De-Capitani and Petrakakis, 2010). Compared with similar occurrences, Lee et al., (2021) obtained temperature of 8000C at three and half-six kbar for incipient (patchy) charnockite of Yeongnam, Korea. The charnockite patches in the host grey gneisses around Ikare are devoid of characteristic sedimentary minerals like sillimanite, cordierite and kyanite which suggest magmatic origin for their precursors.

5. CONCLUSION

Charnockites could be of magmatic, metamorphic or metasomatic origin and occurring in diverse geotectonic settings. The mineral assemblages of quartz, plagioclase (perthite), biotite, hornblende (pargasite - ferropargasite), alkali feldspar (microcline), orthopyroxene (hypersthene - ferrohypersthene) ± clinopyroxene are typical of charnockitic rocks. The accessory minerals are apatite, ilmenite, magnetite and, zircon. Hypersthene in the studied incipient charnockite is poor in aluminum (< 0.1 apfu) typical of pyroxene from granulite facies rocks. Both hornblende and biotite are stable in this rock and thereby foreclose retrogression.

Occurrence of incipient or patchy charnockite often signifies transition zone between amphibolite to granulite facies metamorphic terrains. Geothermobarometric calculations using hornblende-plagioclase and two-feldspar thermometers showed temperature ranges of 7400- 8000C @ five kbar, which is in agreement with thermodynamic modeling using Theriak - Domino software of De-Capitani and Petrakakis, (2010) on one sample that gave a temperature of 8000C. Computed results in this study compared favourably with the works of Lee et al., (2021) on incipient charnockite of Yeongnam massif of Korea. The pressure-temperature ranges obtained for incipient charnockite of Ikare region, indicate a low pressure - high temperature metamorphic conditions.

Acknowledgements

I wish to thank my co -authors, Professor Uwe Altenberger, Dr. Daniel Harlov, Professor Anthony Temidayo Bolarinwa who helped in the preparation of this manuscript. Profound gratitude goes to the duo of Mr. Sunday Olayemi and Mr. Rufus Ajila who assisted during fieldwork around Ikare. Also, I appreciate the entire staff of the Institute of Earth and Environmental Science, University of Potsdam, Golm-Potsdam, Germany who assisted in the petrography and micro-probe analysis used in this work. My profound gratitude goes to management of Tertiary Education Trust Fund (TETfund) Nigeria who provided fund for research visit to the Federal Republic of Germany.

Informed Consent

Not applicable

Ethical approval

Not applicable.

Conflicts of interests

The authors declare that there are no conflicts of interests.

Funding

Tertiary Education Trust Fund (TETfund) Nigeria who provided fund for the research.

Data and materials availability

All data associated with this study are present in the paper.

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