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Petrography and Petrogenesis of Charnockitic Rocks from the Okugbe Area, Southwestern Nigeria

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ABSTRACT

This study analyzes the mineralogical composition and petrographic characteristics, as well as the variations in the properties of charnockitic rocks from the Okugbe area, southwestern Nigeria, in order to constrain the mineralogical characteristics and crystallization history within the context of the regional Pan-African granitoids. Fifteen samples were collected and analyzed using petrographic techniques under both plane-polarized and cross-polarized light, and their modal mineralogical compositions were determined through point counting and assessed statistically. The modal compositions were thereafter classified into the QAPF field. The main minerals are plagioclase (35.65 ± 16.26 vol.%), microcline (25.71 ± 17.16 vol.%), and quartz (25.34 ± 7.01 vol.%), with minor amounts of biotite (9.09 vol.%), hornblende (3.42 vol.%), muscovite (2.96 vol.%), and opaque minerals (0.70 vol.%). Feldspar compositions are the major source of modal variations, with microcline and plagioclase having coefficients of variation of 65.4 and 44.5%, respectively, compared with 26.7% for quartz. QAPF classification shows that 11 samples (73.3%) are monzogranites, two (13.3%) granodiorites, and a single sample each (6.7%) is quartz alkali-feldspar syenite and quartz diorite/tonalite. The petrographic studies show hypidiomorphic-granular and granoblastic textures, perthitic feldspars, twinning in microcline and plagioclase, myrmekitic intergrowths, occasional undulose extinction in quartz, as well as weak alignment of minerals. Local orthopyroxene occurrence in some samples provides the basis for the designation of the charnockitic nature of the rocks despite the predominant QAPF classification of monzogranites. The results show that the Okugbe rocks represent an intrusion with dominantly felsic compositions and a quartz–feldspar-rich character that preserves primary plutonic textures and some sub-solidus equilibration features.

1. INTRODUCTION

Charnockitic rocks are orthopyroxene-bearing felsic to intermediate granitoids that are important rock units in high-grade Precambrian crustal terranes around the world. They represent important lithologies for investigating lower crustal evolution through their record of high-temperature magmatic and metamorphic processes associated with continental crust formation and stabilization (Frost and Frost, 2008). Charnockites and granites are often found side-by-side within the Nigerian Basement Complex and are normally associated with the Pan-African Orogenic events. The association between these two rock types in the field, similarity in age and structural

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features, show a relatively synchronous emplacement in the Pan-African Granitoid suite (Tubosun *et al.*, 1984; Rahaman *et al.*, 1988; Dada *et al.*, 1989; Olarewaju, 2006). Their formation is believed to have occurred by partial melting of the lower parts of the continental crust in high temperatures, as well as involvement of some mantle-derived magma. These rock types are also intruded into the metasedimentary rocks in the Igarra Schist Belt, which shows that the formation involved older supracrustal rocks (Odeyemi 1988; Goodenough *et al.*, 2014; Ogunleye *et al.*, 2019).Their occurrence in granulite-facies terrains provides significant information about crustal differentiation, deep crustal melting, magma evolution, and tectono-metamorphic events associated with Precambrian orogenic cycles (Olarewaju, 2006). Although considerable research has been done in the past few decades, the genesis of charnockitic rocks has remained one of the most contentious issues in igneous and metamorphic petrology. Early research suggested two alternative petrogenetic models for the formation of these rocks: (i) crystallization from high-temperature, relatively anhydrous magmas (Kilpatrick and Ellis, 1992), and (ii) formation through dehydration reactions in granulite-facies metamorphic events involving dehydration and transformation of hydrous granitoids to orthopyroxene-bearing assemblages (Newton, 1992). Recently published research shows that both these end-member models can be considered mutually exclusive and contradictory (Dhanil Dev *et al.*, 2023; Wang *et al.*, 2021; Dziggel *et al.*, 2025; Yang *et al.*, 2025). Many charnockite terrains exhibit complex interactions between mantle heat flow, lower continental crust partial melting, CO_2-rich fluids, and localized metamorphic events, resulting in coexisting magmatic, metamorphic, and hybrid charnockites within the same crustal domain (Dhanil Dev *et al.*, 2023; Wang *et al.*, 2021; Dziggel *et al.*, 2025; Yang *et al.*, 2025). Thus, the focus of research on charnockitic rocks has moved away from petrography to an integrated understanding of crustal evolution, magma generation, and tectonics. Worldwide, charnockitic rocks have been studied extensively in the Eastern Ghats Belt and Southern Granulite Terrane of India, the Rinkian Orogen of Greenland, the Limpopo Belt of southern Africa, the Ribeira Belt of Brazil, the Highland Complex of Sri Lanka, and the Precambrian terranes of Madagascar. The aforementioned studies show significant variation in mineral assemblages, geochemical signatures, pressure-temperature conditions, and tectonic settings of charnockitic rocks (Meshram *et al.*, 2021; Sarkar *et al.*, 2023; Chatterjee *et al.*, 2024; Dziggel *et al.*, 2025). Thus, comparative studies of charnockites in different regions have provided significant insight into the evolution of lower crustal magmatic systems and the geodynamics of Precambrian terranes. In Nigeria, charnockitic rocks are widespread in the Precambrian Basement Complex and are important rock units in the Pan-African Mobile Belt. Charnockitic rocks in Nigeria are commonly found as large plutonic bodies associated with migmatitic gneisses, granites, amphibolites, and high-grade metamorphic rocks. Earlier research has studied the petrography, geochemistry, mineral chemistry, and tectonic significance of these rocks in several locations such as Akure, Ikare, Ado-Ekiti, Okpella, and Igarra (Olarewaju, 2006; Ogunleye *et al.*, 2020; Kupolati *et al.*, 2020; Agoha *et al.*, 2021; Oyeshomo *et al.*, 2025). From these studies, it was found that most charnockites in Nigeria formed during the Pan-African Orogeny (ca. 600 Ma) through extensive reworking of the crust by partial melting, granitoid magmatism, and localized charnockitization (Dada, 1989; Oyeshomo *et al.*, 2025). However, there are still many uncertainties about the variations in mineral assemblages, crystallization history, and the influence of regional variations on the petrographic

characteristics. Okugbe area, located at the northwestern margin of the Anambra Basin, exposes Precambrian Basement Complex rocks overlain unconformably by Upper Cretaceous sediments. Although significant attention has been paid to the adjacent basement terranes, petrographic investigation of the Okugbe charnockitic rocks has not been done in much detail. As a result, the mineralogy, petrographic texture and microstructure, crystallization history and petrogenesis of these rocks have not been established. This has limited regional correlations of Okugbe charnockites with other Pan-African charnockite occurrences and understanding of basement evolution at the transition from the Basement Complex to Anambra Basin. This study aims to fill this gap in current knowledge through detailed petrographic investigation and quantitative modal analysis of charnockitic rocks from the Okugbe area. Objectives of the study include (i) determination of the mineralogical composition and modal proportions of the constituent minerals, (ii) characterization of the petrographic texture and microstructure, (iii) evaluation of the crystallization history and petrogenetic significance of the mineral assemblages inferred from petrographic data, and (iv) comparison of Okugbe charnockites with similar Pan-African occurrences in southwestern Nigeria and some global charnockite terranes. Since the present study is based mainly on petrographic analysis, magma source and tectonic setting are discussed as petrographically supported inferences and not as conclusions.

2. LOCATION AND GEOLOGY OF THE STUDY AREA

The study location (Fig. 1) is situated in Okugbe, which is found in southwestern Nigeria, close to the northwestern part of the Anambra Basin. The study location falls within geographic coordinates ranging from latitude 7°25′10″–7°25′30″N and longitude 7°25′10″–7°25′30″E. This region consists of an undulating terrain with exposed basement rocks. The geology of the area involves Precambrian basement rocks comprising charnockites and granite intrusive bodies that are unconformably covered with Campanian-age sediments of the Lokoja Formation. Fieldwork reveals that the charnockitic rocks are the predominant lithology in the area and are intruded by biotite-hornblende granite, pegmatite dykes, and quartz veins. The basement rocks show weak foliation and are widely outcropping as low-lying ridges and inselbergs. Geological similarities have been identified on the northwestern flank of the Anambra Basin (Ladipo, 1988; Ejeh, 2021; Edegbai *et al.*, 2025). Cross-sectional interpretation along A–B (Fig. 1) shows a continuous charnockitic basement locally intruded by granites.

3. REGIONAL GEOLOGICAL SETTINGS

The study location (Okugbe) belongs to the Precambrian Basement Complex (Igarra schist belt) of Nigeria (Odeyemi 1988; Olarewaju 1999; Ogunyele *et al.*, 2020). The Nigerian Basement Complex lies within the Pan-African Trans-Saharan Mobile Belt that is located between the West African and Congo cratons and south of the Tuareg shield (Woakes *et al.* 1987; Goodenough *et al.*, 2014) (Fig. 2a). The Nigerian Basement Complex consists of three major lithological associations, namely the Migmatite-Gneiss Complex, the low-grade metasediments and metavolcanic rocks of the Schist Belts, and the Older Granite suite (Ogunleye *et al.*, 2020).

The Migmatite-Gneiss Complex is represented by rocks ranging in age from Archean-Paleoproterozoic to Neoproterozoic (Grant 1970; Rahaman 1988; Dada 1998; Kröner *et al.*, 2001; Ekwueme 2003a; Okonkwo and Ganev

2015). The Schist Belts include mainly the low-grade metasediments

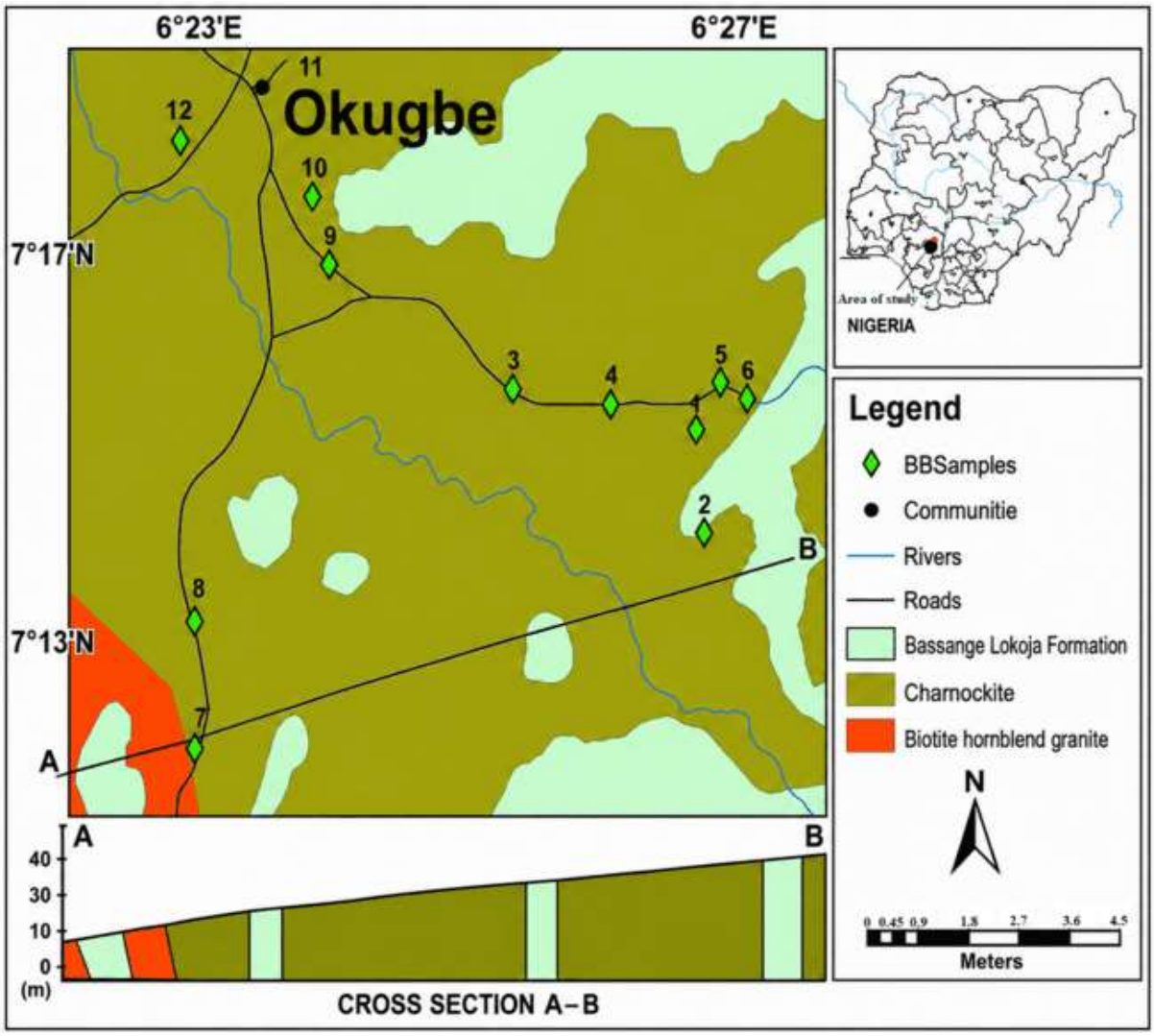


Figure 1. Geological map of the study area.

and metavolcanic rocks of Neoproterozoic age, and their ages fall mostly within the range of 690-489 Ma (Turner 1983; Elueze 1988; Odeyemi 1988; Rahaman 1988; Omitogun *et al.*, 1991;Caby and Boessé 2001; Danbatta 2008; Fagbohun *et al.*, 2020). The older lithological formations have been further intruded by the Older Granite suite, which is predominantly of Pan-African age (Ferré *et al.*, 2002; Ekwueme 2003b; Adetunji *et al.*, 2018; Girei *et al.*, 2019; Ibe and Obiora 2019; Bute *et al.*, 2019). Radiometric ages have constrained the time of emplacement of the Pan-African granites at about 650-580 Ma (Tubosun *et al.* 1984; Rahaman *et al.*, 1991; Dada *et al.*, 1993; Dada 1998; Goodenough *et al.*, 2014; Bute *et al.*, 2019). The geological evolution of the Nigerian Basement Complex has involved many tectonic stages associated with repeated deformations in the Precambrian (Rahaman 1988; Odeyemi 1981; Ajibade *et al.*, 1987; Ekwueme and Kalsbeek 2014). The successive tectonic events have resulted in a complex structure. Though the studied area transits the Anambra Basin, the studied rocks belong to the Precambrian Basement Complex and do not form part of the sedimentary basin succession. The

Anambra Basin (Fig. 3) was formed after Santonian tectonic inversion of the Lower Benue Trough in the Late Cretaceous and later deposited Campanian to Paleogene sedimentary rocks, such as Lokoja, Patti, Mamu, Ajali, Nsukka, Imo, and Ameki Formations (Murat, 1972; Ladipo, 1988; Ejeh, 2021). In the Okugbe area, the crystalline basement represents the underlying structural basement to the unconformable overlying Campanian Bassange-Lokoja Formation. The basement-sedimentary contact marks the change from Precambrian crystalline basement to Cretaceous sedimentary cover, giving important information on post-Pan-African exhumation and erosion in the basin development process. The proximity of the basement rocks to the overlying sedimentary succession in the area makes the area ideal for studies of the geological evolution of the Basement Complex-Anambra Basin transition (Ejeh, 2021; Edegbai *et al.*, 2025). Igarra Schist Belt is a significant component of the southwestern Nigerian Basement Complex, composed of three main lithologic associations: (i) Migmatite–Gneiss Complex, (ii) Igarra metasedimentary series, and (iii) Pan-African granitoids (Odeyemi, 1988; Omitogun *et al.*, 1991). Migmatite-Gneiss Complex is made up of migmatites, biotite and biotite-hornblende gneisses, granite gneisses, and remains of older metasediments. It forms the basement upon which Igarra metasedimentary rocks were deposited and is the oldest lithologic association, ranging in age from Archean to Neoproterozoic. Contacts between migmatite-gneiss basement and the metasedimentary series are mainly fault-controlled (Odeyemi 1988; Jimoh *et al.*, 2016). Igarra metasedimentary rocks cover an area of about 3000 km² and consist of low-grade metamorphosed sedimentary rocks, namely, schists, calc-silicate gneisses, marbles, metaconglomerates, quartzites, and banded iron formations (Okeke and Meju 1985; Odeyemi 1988; Adegbuyi *et al.*, 2017). Turner (1983) first classified the Igarra Schist Belt as Kibaran based on its lithology, structure, and intrusive rocks. However, Rahaman *et al.*, (1988) refuted this hypothesis, based on the radiometric data, suggesting that Schist Belts in Nigeria, including Igarra, are mainly Neoproterozoic, with the bulk of ages ranging from 690 to 489 Ma. At the same time, they suggested that sedimentation and volcanism might have begun in the early Pan-African times, 800 Ma ago. Odeyemi (1988) suggested that the Igarra and Egbe Schist Belts can be considered as a paired metamorphic belt, despite the considerable difference in lithology of these two Schist Belts. Egbe Belt includes a volcano-sedimentary succession with abundant metavolcanic rocks, in particular, amphibolites and amphibole schists (Olobaniyi and Annor 2003). On the contrary, the lack of metavolcanic rocks and the presence of conglomeratic strata in the Igarra Schist Belt are evidence of primarily clastic sedimentation and tectonic instability of the sedimentary basin (Odeyemi 1988; Omitogun *et al.*, 1991). The structural setting of the Igarra Schist Belt is rather complicated. Geological mapping revealed at least four antiforms and four corresponding synforms with fold axes trending approximately N-S, as well as four major fault zones. Metamorphic facies of the Igarra Schist Belt are mainly represented by greenschist facies; however, in some places, metamorphic grade rises to lower amphibolite facies, especially in the eastern part of the belt (Omitogun *et al.*, 1991).

4. METHODOLOGY

A total of fifteen (15) representative samples of fresh rocks were collected from outcrop exposures of charnockitic rocks within the study area during geological mapping. The geographic coordinates of each sampling outcrop were obtained using a hand-held GPS device.

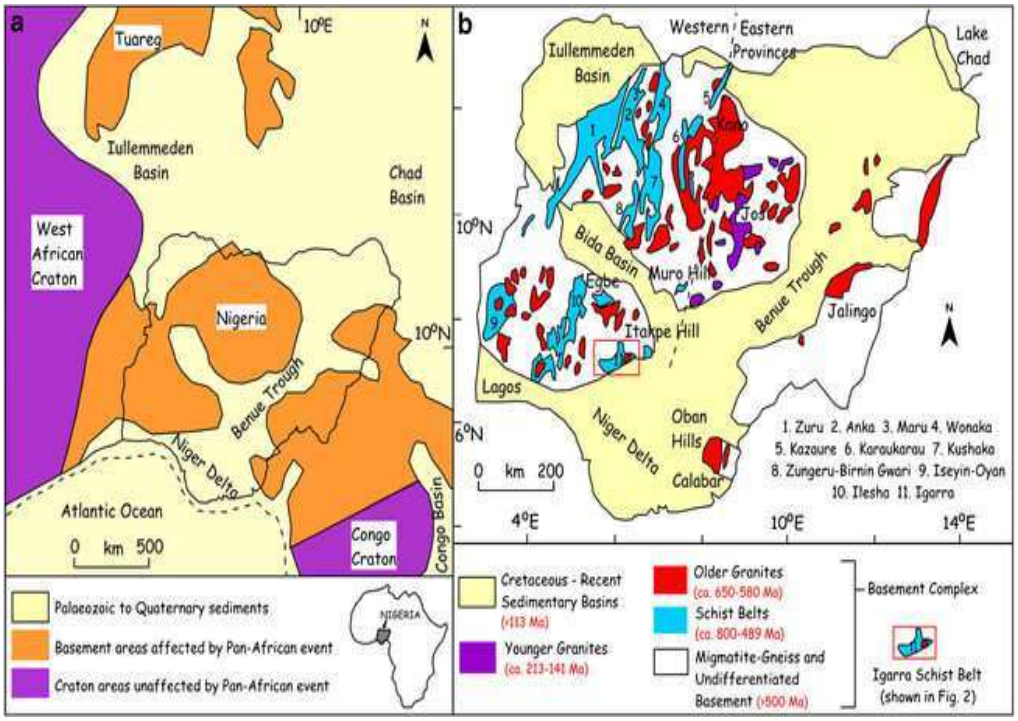


Figure 2. (a) Geological framework of Nigeria in the Pan-African Trans-Saharan Mobile Belt, regionally located between the West African and Congo Cratons; (b) Geologic map of Nigeria depicting the spatial occurrence of the Basement Complex, Younger Granites, and sedimentary basins (Ogunleye *et al.* 2020; adapted from Woakes *et al.*, 1987).

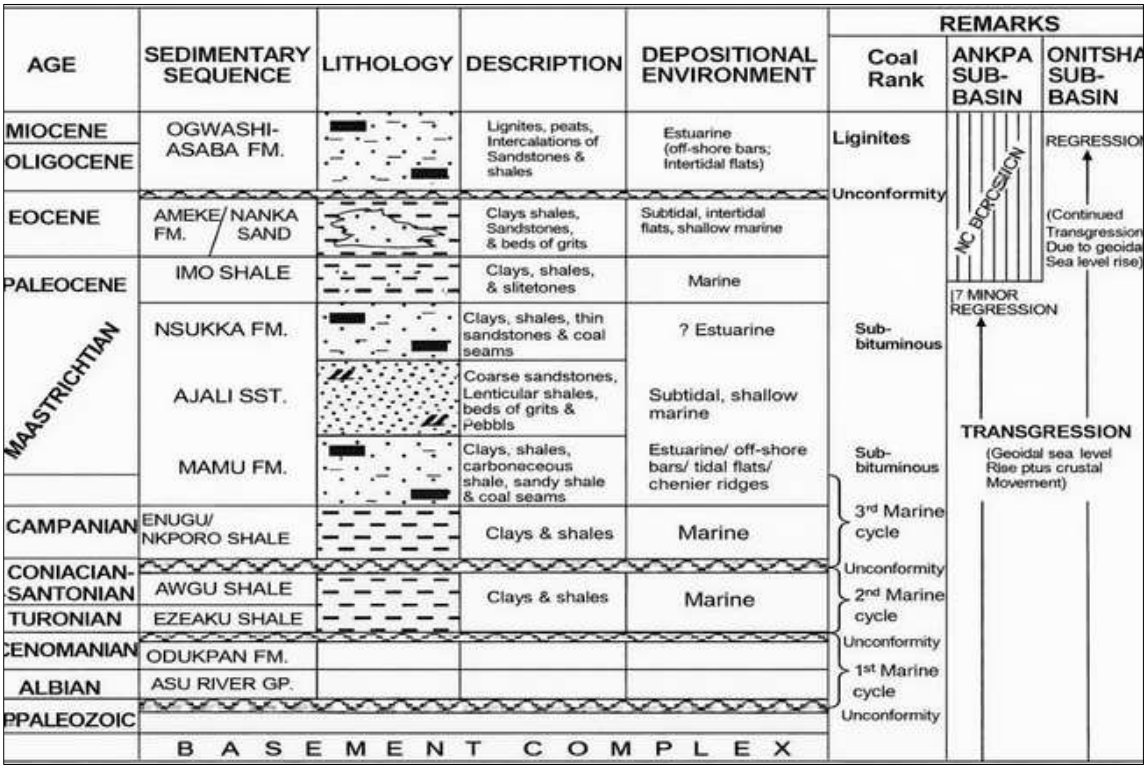


Figure 3. Stratigraphy of the Anambra Basin (After Ladipo, 1988, and Akande *et al.*, 1992; modified by Uzoegbu *et al.*, 2013).

Standard petrographic thin sections were made in the Petrology Laboratory, Department of Geology, University of Benin, Nigeria, according to standard procedures outlined by Hutchison (1974), Tucker (2001), and Ogunleye *et al.*, (2020). The rock samples were sawn into billets, mounted on a glass slide with thermosetting resin, then ground and polished to a thickness of 30 µm to make precise mineral identification under transmitted light. Examination of the thin sections was done using a Polarizing Transmitted Light Petrographic Microscope (Unitron 12100 model) fitted with a digital imaging device (Konica digital camera). Thin sections were studied under Plane Polarized Light (PPL) and Cross Polarized Light (XPL) to identify minerals, optical properties, mineral-textural relations, alteration features, and deformation features. Representative photomicrographs were taken and annotated with principal minerals and important petrographic textures, such as perthitic intergrowths, myrmekite, twinning, foliation, fractures, and grain boundary relations. Modal analysis of the mineral compositions in the rocks was done by point counting, where approximately 200 points were counted in each thin section to provide representative data of mineral abundance. Classification of the rocks was based on their QAPF proportions of quartz (Q), alkali feldspar (A), and plagioclase (P) according to the QAPF rock classification diagram of Streckeisen (1976) for plutonic rocks. Descriptive statistics, such as mean, standard deviation, minimum, maximum, and coefficient of variation, were calculated for all mineral phases to quantify the mineralogical variations in the investigated rocks. Petrographic interpretations were made in conjunction with published data on Nigerian and worldwide charnockites to infer the crystallization history and petrogenesis of the rocks. Since this study is largely petrographic in nature, interpretations regarding the magma source and tectonic setting are made as geological inferences which need to be confirmed by additional whole-rock geochemical, isotopic, and geochronological studies (Frost and Frost, 2008; Dhanil Dev *et al.*, 2023; Dziggel *et al.*, 2025).

5. DISCUSSION OF RESULTS

5.1 Modal Mineralogy

The results of the quantitative modal analysis (Table 1) of the fifteen analyzed samples reveal the main components of the rocks as plagioclase, quartz, and microcline, with subordinate components being biotite, hornblende, muscovite, and opaque minerals. Plagioclase constitutes the largest proportion of the analyzed samples (from 4.0 to 82.0 vol.% with the mean value of 35.65 ± 16.26 vol.%). Microcline is represented by amounts of 5.1 to 82.1 vol.% (with the mean value of 25.71 ± 17.16 vol.%), and quartz – from 10.1 to 35.7 vol.% (with the mean value of 25.34 ± 7.01 vol.%). The major components of the mafic minerals are biotite and hornblende with average contents of 9.09 and 3.42 vol.%, respectively. Muscovite and opaque minerals constitute only 2.96 and 0.70 vol.%, respectively. High contents of quartz and feldspar (both constitute a major part of the modal composition of the samples) suggest that the investigated rocks are characterized by a felsic granitoid nature. High content of quartz in the investigated samples is quite comparable; however, different feldspars exhibit quite high variability in modal composition. In particular, this variability is demonstrated in LP-E and LP-N samples with high amounts of microcline (82.1 vol.%) and plagioclase (82.0 vol.%), respectively. Considering the predominance of quartz and feldspars (>85% of the modal composition). The variation in the proportions of plagioclase and microcline between the different samples could be attributed to local magmatic differentiation and minor heterogeneity during crystallization of the same magma source,

and not to different magma source(s). Such modal compositions were found in Pan-African charnockites of Okpella, Akure, Ikare, and other regions of southwest Nigeria (Ogunleye *et al.*, 2020; Kupolati *et al.*, 2020; Oyeshomo *et al.*, 2025).

Table 1. Modal composition of minerals in rock samples.

SAMPLE CODE	QUARTZ	MICROCLINE	PLAGIOCLASE	BIOTITE	HORNBLENDE	MUSCOVITE	OPAQUE
LP-A	29.7	20.8	30.5	10.6	5.4	2.2	0.8
LP-B	26.1	22.6	34.2	8.6	5.8	2.0	0.7
LP-C	27.4	25.1	32.2	8.5	3.0	3.2	0.6
LP-D	24.3	22.8	30.9	14.2	4.2	2.9	0.7
LP-E	10.2	82.1	4.0	--	--	3.1	0.6
LP-F	28.5	23.0	34.2	9.4	2.0	2.1	0.8
LP-G	29.6	22.4	33.5	8.7	--	5.1	0.7
LP-H	28.1	22.6	33.1	9.9	3.2	2.3	0.8
LP-I	27.6	21.1	35.0	12.5	3.1	3.1	0.7
LP-J	28.2	22.6	30.5	10.3	4.0	3.6	0.8
LP-K	25.2	21.6	44.7	5.6	--	2.9	--
LP-L	29.2	30.8	26.9	7.1	2.1	3.2	0.7
LP-M	35.7	16.0	42.9	2.3	--	3.1	--
LP-N	10.1	5.1	82.0	--	--	2.8	--
LP-O	24.6	22.2	35.1	12.0	3.4	2.1	0.6
Mean	25.34	25.71	35.65	9.09	3.42	2.96	0.7
Standard deviation	7.01	17.16	16.26	3.18	1.15	0.78	0.07
Coefficient of variation	26.7	65.4	44.5	33.4	34.7	26.9	11.2
Sample Variance	49.17	294.72	264.47	10.12	1.33	0.61	0
Range	25.6	77	78	11.9	3.8	3.1	0.2
Minimum	10.1	5.1	4	2.3	2	2	0.6
Maximum	35.7	82.1	82	14.2	5.8	5.1	0.8

5.1.1 Mineralogical variability and petrogenetic significance

Further statistical analysis (Table 1) shows that feldspars constitute the main source of modal heterogeneity. Microcline possesses the largest coefficient of variation (65.4%), while plagioclase possesses the second largest (44.5%). The lowest coefficient of variation (26.7%) occurs for quartz. Moderate coefficients of variation of 33.4 and 34.7% occur for biotite and hornblende, respectively. On the other hand, opaque minerals show a low coefficient of variation (11.2%). Since there is a significant variation in the abundance of feldspars, particularly between LP-E and LP-N, the rocks possess modal heterogeneity. This may be due to differences in mineral proportions during crystallization, accumulation of specific minerals, or variations in composition in the intrusive body. Since there is little variation in quartz and opaque minerals, the major variation in rock composition may likely occur due to the relative proportion of alkali feldspar and plagioclase, and not the general quartz richness. The small amounts of biotite, hornblende, and muscovite, as well as the dominance of quartz and feldspars, are consistent with the felsic nature of the rocks in the investigated assemblage. However, insufficient modal data have been obtained to uniquely determine the magma source, tectonic setting, and pressure–temperature conditions.

5.1.2 QAPF Classification of the crystalline rocks

According to the QAPF classification diagram (Fig. 4) (Streckeisen, 1976), it can be said that the investigated Okugbe intrusive rocks are composed mainly of felsic granitoids. Out of the fifteen samples analyzed, eleven (73.3%) are monzogranite, two (13.3%) are granodiorite, one sample (6.7%) is quartz alkali feldspar syenite, and another sample (6.7%) is quartz diorite/tonalite (Fig. 4). The preponderance of monzogranite in the

analyzed samples is due to quartz, alkali feldspar, and plagioclase contents in these samples. Two samples of granodiorites and quartz diorites/tonalites show higher amounts of plagioclase, while one sample is rich in alkali feldspar, which indicates some localized magmatic differentiation within the intrusive suite. According to QAPF classification, it can be seen that the investigated samples are silica-saturated granitoids which fall into the category of Pan-African Basement Complex in southwestern Nigeria (Rahaman, 1988; Dada, 1989). Even though they are compositionally mainly monzogranite but presence of orthopyroxene in some thin sections (Fig, 6g and m′) has been used to classify them as charnockitic granitoids because the QAPF classification classifies the rocks according to mineral modes and not based on orthopyroxene-bearing mineral assemblages, as in the case of charnockites (Streckeisen, 1976; Frost and Frost, 2008).

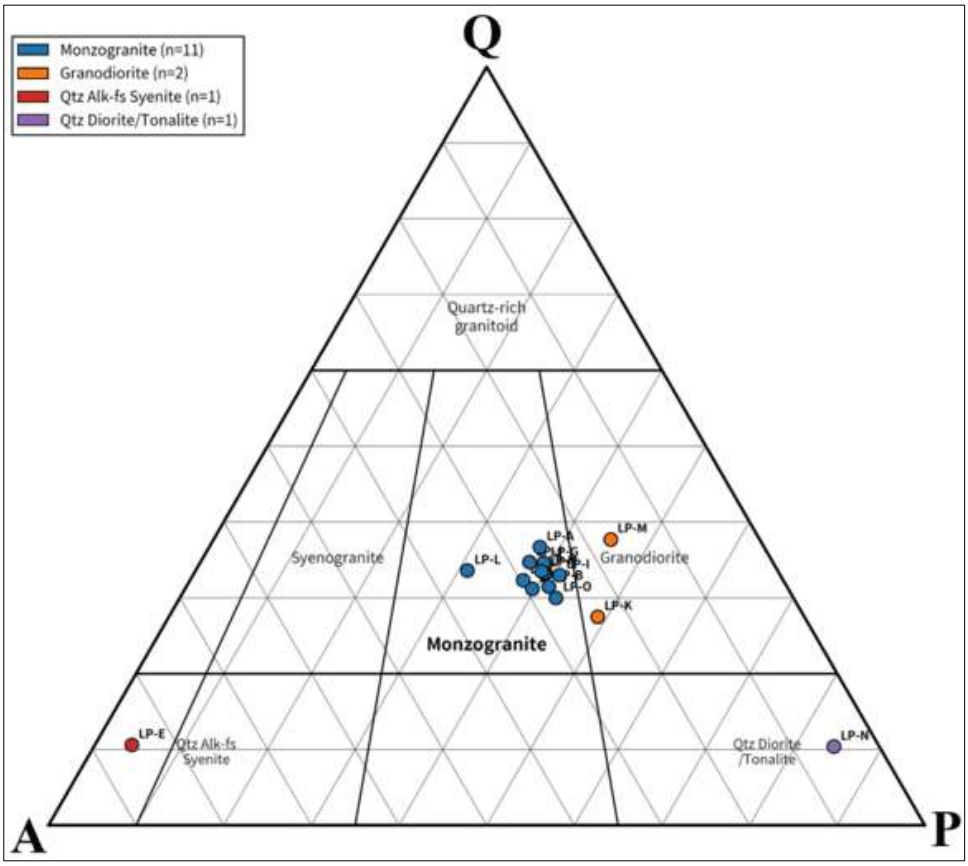


Figure 4. Diagram showing QAPF (Quartz-Alkaline Feldspar-Plagioclase) classification of the studied crystalline rocks according to Streckeisen (1976).

5.2. Petrography

Based on the petrographic analysis, it was revealed that the studied rocks are composed of minerals and textures corresponding to the felsic charnockitic granitoids of the Precambrian basement complex of Nigeria. The main rock-forming minerals include quartz, plagioclase, microcline, biotite, hornblende, muscovite, and opaque minerals. Local occurrences of orthopyroxene were recorded in some thin sections (Fig. 6g, m and m′); however, it is not abundant enough to dominate the mineral composition. Quartz occurs as anhedral interstitial grains and shows weak undulose extinction (Fig. 5h; Fig. 6j, m′ and n) when viewed in crossed polarizers. The undulose extinction is usually considered to

result from limited post-crystallization intracrystalline deformation induced by subsequent tectonic stress, without dynamic recrystallization (Passchier and Trouw, 2005). Plagioclase crystals are mainly subhedral and show well-developed albite twinning (Figs. 5 and 6), suggesting crystal growth or stress (Frost and Frost 2008). Microcline (Fig. 5c) shows characteristic tartan twinning and perthitic intergrowths as a result of exsolution of sodic feldspar during subsolidus cooling (Waldron *et al.*, 1993). The perthitic texture is generally used as evidence of slow cooling within deep-crustal granitoids (Vernon, 2004). Biotite is the most abundant ferromagnesian mineral, and it occurs as subhedral brown pleochroic flakes intergrown with feldspars and quartz. Hornblende occurs in much lesser amounts, being represented by subhedral green crystals which sometimes show weak mineral alignment. The combination of hornblende and biotite implies the formation of the felsic rocks from relatively dry to moderately hydrous magma (Frost and Frost, 2008; Oyeshomo *et al.*, 2025). Muscovite is found in very small amounts, and it is considered to be a late-stage magmatic or subsolidus mineral formed during the late stages of cooling. Myrmekitic intergrowths occurring along the boundaries between plagioclase and microcline are recorded in several thin sections (Fig. 6m and m′). The myrmekite is a result of the subsolidus replacement texture, and it forms during alkali metasomatism or deformation-assisted recrystallization during cooling (Ogunleye *et al.*, 2020; Phillips, 1974; Vernon, 2004). Therefore, the presence of myrmekite implies that limited subsolidus re-equilibration occurred, affecting parts of the plutonic body without altering the primary mineral assemblage. Foliation observed in some samples is mainly controlled by the preferred orientation of biotite and hornblende. The foliation is usually discontinuous and does not affect the primary hypidiomorphic-granular texture. This suggests that deformation occurred after the completion of crystallization, but it was relatively weak. Additionally, the formation of foliations, intergranular cracks, and fractures in the studied rocks indicates deeply penetrative deformation. Consequently, the studied rocks are mainly characterized by igneous textures with tectonic overprint. Overall, the petrographic characteristics imply that the studied rocks formed as coarse-grained felsic intrusive rocks and then experienced limited subsolidus recrystallization and weak deformation. Similar mineral assemblages, perthitic feldspars, myrmekite textures, and tectonic fabrics were described for the charnockites of Okpella, Akure, Ikare, and Igarra of the southwestern Nigerian Basement Complex (Ogunleye *et al.*, 2020; Kupolati *et al.*, 2020; Oziegbe, 2023; Oyeshomo *et al.*, 2025).

5.3. Petrogenesis

The information obtained from the modal mineralogy and petrographic features imposes constraints on the crystallization history of the Okugbe charnockitic rocks. The presence of quartz and feldspars, in addition to the low amount of mafic minerals, shows that the studied rocks are evolved felsic granitoids. Their hypidiomorphic-granular texture implies that they crystallized slowly in the upper-to-middle crust following the emplacement of a plutonic magma. It can be inferred from the petrography that the crystallization sequence started with the crystallization of plagioclase and biotite, followed by alkali feldspar and interstitial quartz.

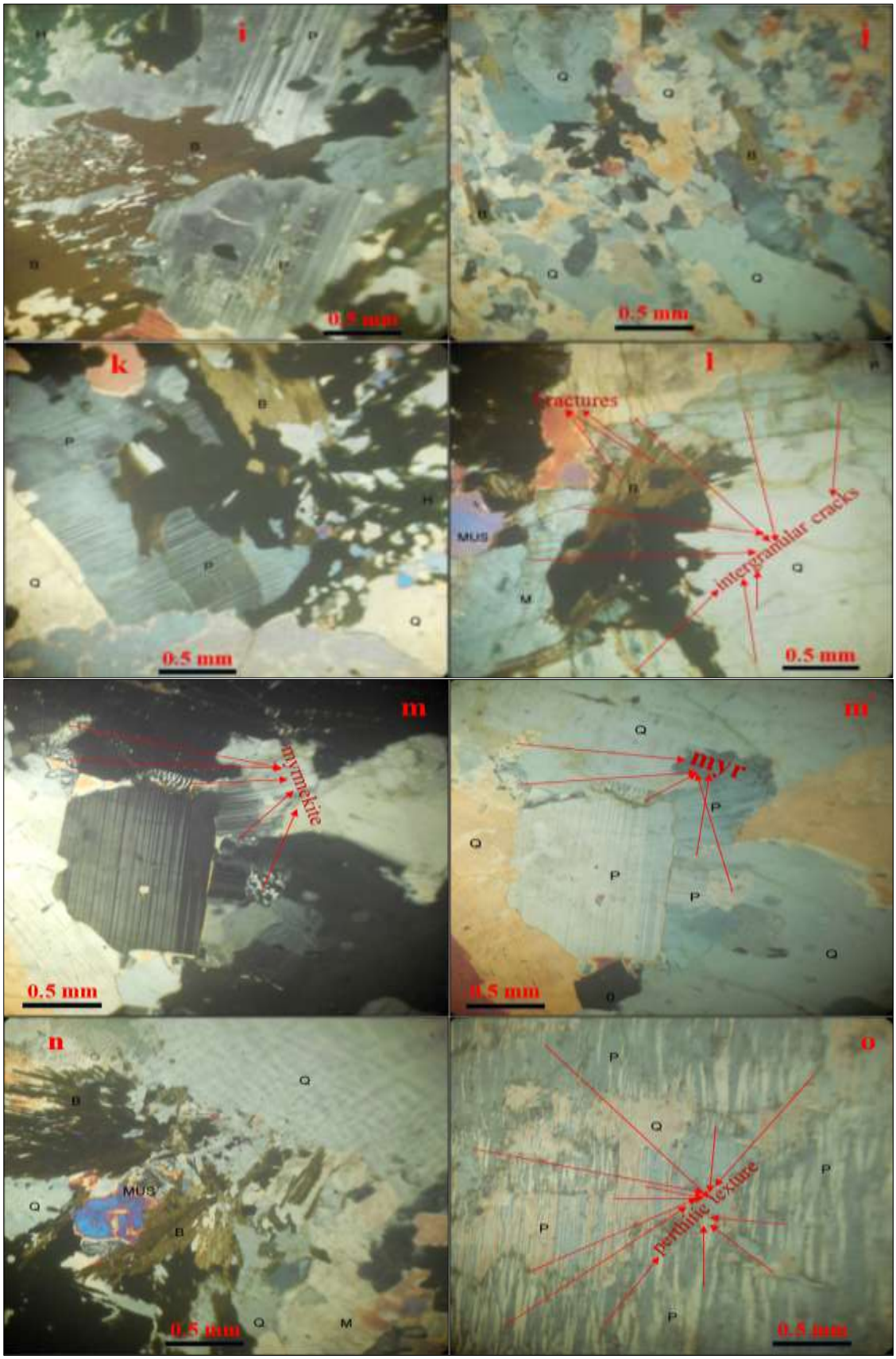


Figure 5. Photomicrographs of rock specimens a – h under XPL.

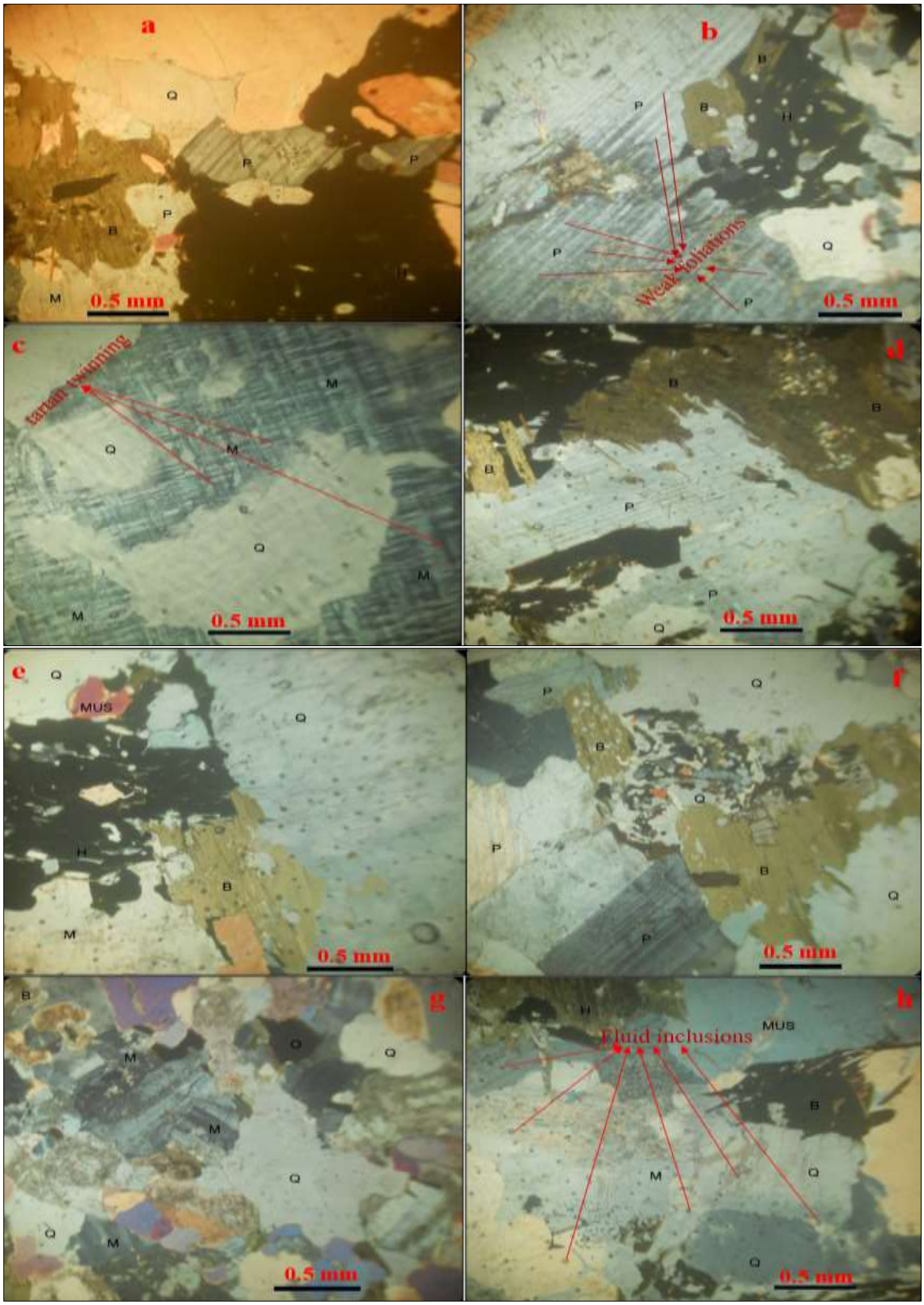


Figure 6. Photomicrographs of rock specimens i – o, and m′ under PPL and XPL, respectively.

The perthitic structure of feldspar implies protracted subsolidus cooling, while the myrmekitic structure is indicative of K-metasomatism and/or progressive sub-magmatic deformation in the rock (Ogunleye *et al.*, 2020; Clemens and Stevens, 2026). Minor undulose extinction and alignment of minerals further imply deformation occurred after the crystallization of the pluton. The coexistence of biotite, hornblende, and occasionally preserved orthopyroxene shows crystallization at relatively high temperatures similar to the conditions in most Pan-African charnockitic intrusions (Frost and Frost, 2008; Dhanil Dev *et al.*, 2023). However, it should be pointed out that the petrography of the rocks cannot constrain the magma source, crystallization pressure, tectonic setting, or specific pressure-temperature conditions. In this way, any interpretations regarding the magma genesis are not definite until they are confirmed by whole-rock geochemical, isotope geochemistry, mineral chemistry, and geochronological investigations. The petrography of the Okugbe charnockites is in good accordance with the previously proposed models of formation of the Nigerian charnockites as a result of the high-temperature melting and differentiation of the lower continental crust during the Pan-African Orogeny (Olarewaju, 2006; Ogunleye *et al.*, 2020; Oyeshomo *et al.*, 2025). Contemporary studies of the petrogenesis of the charnockites reveal that such magmas might form through the interaction involving mantle-derived thermal input, lower-crustal anatexis, dehydration melting, and activity of the CO_2-rich fluids (Dhanil Dev *et al.*, 2023; Dziggel *et al.*, 2025; Yang *et al.*, 2025). However, the mineral assemblages identified in the rocks of Okugbe are consistent with these processes, but without additional geochemical data, they cannot distinguish among the possible genetic models. The comparison of the petrography of the Okugbe rocks with the petrography of charnockitic rocks in Okpella, Akure, Ikare, and Igarra shows their similarities concerning the modal composition, dominance of feldspars in the mineralogical composition, the presence of perthitic texture and myrmekitic intergrowths, as well as weak tectonic overprinting (Ogunleye *et al.*, 2020; Kupolati *et al.*, 2020; Oyeshomo *et al.*, 2025). Similar petrographic features were also identified in the Eastern Ghats Province in India, in the Southern Granulite Terrane, in the Rinkian Orogen of Greenland, and in Brazilian Precambrian terranes, where the felsic charnockitic plutons are considered products of deep-crustal magmatism with varying metamorphism (Meshram *et al.*, 2021; Sarkar *et al.*, 2023; Chatterjee *et al.*, 2024; Dziggel *et al.*, 2025). Thus, it can be said that the Okugbe charnockitic rocks represent felsic plutonic rocks, which preserve primarily igneous petrographic features with some evidence of subsolidus re-equilibration and weak deformation. Although the petrography indicates crystallization at relatively high temperatures similar to other Pan-African charnockitic suites, their definite interpretation needs to be made on the basis of the results of whole-rock geochemistry, isotope geochemistry, mineral chemistry, thermobarometry, and zircon U-Pb geochronology.

5. CONCLUSION AND RECOMMENDATIONS

Detailed petrographic study and modal analysis of fifteen rock samples from the Okugbe area yielded novel constraints about the nature and evolution of the charnockitic rocks in the studied location. The main mineral constituents include plagioclase, microcline, and quartz, together with biotite, hornblende, muscovite, and opaque minerals, thus confirming the overall felsic composition of the investigated rocks. The most

important variation in the modal composition of the studied samples is determined by the amount of microcline and plagioclase minerals, with coefficients of variation of 65.4% and 44.5%, respectively, while quartz shows a smaller coefficient (26.7%). According to the QAPF classification, monzonitic composition prevails (73.3%) and is accompanied by less abundant granodioritic, quartz alkali-feldspar syenitic, and quartz dioritic/tonalitic rock types. The observed hypidiomorphic-granular to granoblastic texture, perthitic feldspars, myrmekitic intergrowths, twinned feldspar, quartz undulose extinction, and weak mineral alignment are indicative of primary plutonic crystallization with some subsequent sub-solidus re-equilibration and weak deformation. Although monzonitic rocks prevail in the classification, the presence of orthopyroxene in several samples supports the charnockitic classification based on the petrographic study. The most significant contribution of this study includes the creation of a detailed petrographic and quantitative modal mineralogy of the Okugbe charnockites that can be used as a basis for comparison of this particular group of rocks with other Pan-African charnockites and granitoids in southwestern Nigeria. However, the information about the petrography and mineralogical composition cannot be used to solve such problems as the determination of the magma source, tectonic affinity, pressure-temperature conditions, and emplacement age. Therefore, future studies must include the analysis of whole-rock major, trace, and rare earth elements; mineral composition; Sr-Nd-Pb and zircon Lu-Hf isotope systematics; and zircon U-Pb geochronology.

REFERENCES

Adegbuyi O, Ogunyele AC, Odindu M, Erinfolami TG (2017). Geochemical characteristics and petrogenesis of basement rocks in Idoani area, Ondo State, southwestern Nigeria. Inter J Adv Geosci 5(2):102–108. https://doi.org/10.14419/ijag.v5i2.8377

Adegoke, O.S., Ako, B.D., and Enu, E.I. (1980). Geotechnical investigations of the Ondo State bituminous sands. Vol. 1. Geology and reserve estimate. Rept. Geological Consulting Unit, Dept. of Geology, University of Ife, pp 257.

Adetunji A, Olarewaju VO, Ocan OO, Macheva L, Ganev VY (2018). Geochemistry and U-Pb zircon geochronology of Iwo quartz potassic syenite, southwestern Nigeria: constraints on petrogenesis, timing of deformation and terrane amalgamation. Precambrian Res 307:125–136. https://doi.org/10.1016/j.precamres.2018.01.015

Ajibade AC,Woakes M, Rahaman MA (1987). Proterozoic crustal development in the Pan-African regime of Nigeria. In: Kröner A (ed) Proterozoic lithospheric evolution 17. https://doi.org/10.1029/GD017p0259

Akande, S.O., Hoffknecht, A., Erdtmann, B.D., (1992). Upper Cretaceous and Tertiary Coals from southern Nigeria: Composition, rank, depositional environments, and their technological properties. Bull. Nig. Assoc. Petrol. Expl., 7,26-38.

Bute SI, Yang X, Cao J, Liu L, Deng J, Haruna IV, Girei MB, Abubakar U, Akhtar S (2019). Origin and tectonic implications of ferroan alkali-calcic granitoids from the Hawal Massif, East-Eastern Nigeria terrane: clues from geochemistry and zircon U-Pb-

Hf isotopes. Inter Geol Rev 62(2):129–152. https://doi.org/10.1080/00206814.2019.1593250

Caby R, Boessé JM (2001). Pan-African nappe system in Southwest Nigeria: the Ife-Ilesha schist belt. J Afr Earth Sci 33:211–225.

Clemens, J. D., & Stevens, G. (2026). Most ordinary granitic magmas are born as charnockites or become charnockites during magma ascent: Evidence for the prior existence of orthopyroxene and implications of high magma temperatures and inefficient crystal–melt separation. Mineralogy and Petrology, 120, 381–393. https://doi.org/10.1007/s00710-026-00990-0.

Dada SS (1998). Crust-forming ages and Proterozoic crustal evolution in Nigeria: a reappraisal of current interpretations. Precambrian Res 87: 65–74.

Dada SS, Tubosun IA, Lancelot JR, Lar AU (1993). Late Archaean U-Pb age for the reactivated basement of northeastern Nigeria. J Afr Earth Sci 16(4):405–412.

Dada, S.S. (1989). Crust-forming ages and Proterozoic crustal evolution of Nigeria.

Dada, S.S., Lancelot, J.R., Briqueu, L., (1989). Age and origin of the annular charnockitic complex at Toro, Northern Nigeria: U-Pb and Rb-Sr evidence. J Afr Earth Sci 9(2):227–234.

Danbatta UA (2008). A review of the evolution and tectonic framework of the schist belts of Western Nigeria, West Africa. Afr Geosci Rev 15(2):145–158

Dhanil Dev, S.G., Shaji, E., Santosh, M., Tsunogae, T., Prasanth, R.S. (2023). Mesoarchean charnockites from the Coorg Block, Southern India: Petrology, geochemistry and tectonic implications, Geosystems and Geoenvironment, Volume 2, Issue 1, https://doi.org/10.1016/j.geogeo.2022.100134.

Dziggel, A., Bramm, L., Kokfelt, T.F., Grocott, J., Diener, J.F.A. (2025). Preservation of igneous and metamorphic charnockites in the Paleoproterozoic Prøven Igneous Complex, Rinkian Orogen, central West Greenland, Precambrian Research, Volume 417, 107634, ISSN 0301-9268, https://doi.org/10.1016/j.precamres.2024.107634.

Edegbai, A.J., Eigbiluese, O.P. & Edosomwan, F.O. (2025). Campanian alluvial processes in SW Anambra Basin, Nigeria: insights from sedimentology and lithofacies analysis of the Lokoja Formation. Arab J Geosci 18, 189. https://doi.org/10.1007/s12517-025-12334-x

Ejeh, O.I, (2021). Geochemistry of rocks (Late Cretaceous) in the Anambra Basin, SE Nigeria: insights into provenance, tectonic setting, and other palaeo-conditions. https://doi.org/10.1016/j.heliyon.2021.e08110

Ekwueme BN (2003a). Geochemistry of crystalline basement rocks, SW Ugep, Nigeria. Glob J Geol Sci 1(2):1–7

Ekwueme BN (2003b) The Precambrian geology and evolution of the southeastern Nigerian Basement

Complex. University of Calabar Press

Ekwueme BN, Kalsbeek F (2014). U-Pb geochronology of metasedimentary schists in Akwanga area of northcentral Nigeria and its implications for the evolution of the Nigerian Basement Complex. Glob J Geol Sci 12(1):21–30. https://doi.org/10.4314/gjgs.v12i1.3

Fagbohun BJ, Omitogun AA, Bamisaiye OA, Ayoola FJ (2020). Remote detection and interpretation of structural style of the Zuru Schist Belt, Northwest Nigeria. Geocarto Inter:1–21. https://doi.org/10.1080/10106049.2020.1753822

Ferré EC, Gleizes G, Caby R (2002) Obliquely convergent tectonics and granite emplacement in the Trans-Saharan belt of Eastern Nigeria: a synthesis. Precambrian Res 114:199–219

Frost, B.R., Frost, C.D. (2008). On charnockites. Gondwana Research.

Girei MB, Najime T, Ogunleye PO (2019). Geochemical characteristics and origin of the Neoproterozoic high-K calc-alkaline granitoids in the northern part of Mandara hills, northeastern Nigeria. Acta Geochim 39:337–354. https://doi.org/10.1007/s11631-019-00365-7

Goodenough, K.M., Lusty, P.A.J., Roberts, N.M.W., Key, R.M., Garba, A., (2014). Post-collisional Pan-African granitoids and rare metal pegmatites in western Nigeria: age, petrogenesis, and the 'pegmatite conundrum'. Lithos 200:22–34. https://doi.org/10.1016/j.lithos.2014.04.006

Grant NK (1970). Geochronology of Precambrian basement rocks from Ibadan, southwestern Nigeria. Earth Planet Sci Lett 10:29–38.

Hutchinson, C.S., (1974). Laboratory Handbook of Petrographic Techniques. xxvii+527 pp., 146 figs. Wiley & Sons, New York, London, Sydney, Toronto.

Ibe CU, Obiora SC (2019). Geochemical characterization of granitoids in Katchuan Irruan area: further evidence for peraluminous and shoshonitic compositions and post-collisional setting of granitic rocks in the Precambrian Basement Complex of Nigeria. Acta Geochim 38:734–752. https://doi.org/10.1007/s11631-019-00318-0

Jimoh OA, Ariffin KS, Hussin HB, Habeeb AA (2016). Characterization and assessment of Okpella metacarbonate deposit in Nigeria. Carbonates Evap 32:513–524. https://doi.org/10.1007/s13146-016-0308-3

Kilpatrick, J.A., Ellis, D.J. (1992). C-type magmas: Igneous charnockites.

Kröner A, Ekwueme BN, Pidgeon RT (2001). The oldest rocks in West Africa: SHRIMP zircon age for early Archean migmatitic orthogneiss at Kaduna, northern Nigeria. J Geol 109:399–406

Kupolati, D., Amosun, J., Olayanju, G., Oyebamiji, A., Fagbemigun, T. (2020). Geophysical and Petrographical Study of Apatapiti Charnockitic Rock, Akure, Southwestern Nigeria, Iraqi Journal of Science, vol. 61, no. 6, pp. 1328–

1344, Jun. 2020, doi: 10.24996/ijs.2020.61.6.11.

Ladipo, K.O., (1988). Paleogeography, sedimentation and tectonics of the Upper Cretaceous Anambra Basin, southeastern Nigeria. Jour. Afri. Earth Sci., 7, 865-871.

Murat, R.C. (1972). Stratigraphy and Paleogeography of the Cretaceous and lower Lower Tertiary 514 in Southern Nigeria in: Dessauvagie, T. F. J. (Ed.)

Newton, R.C. (1992). Charnockitic alteration and CO2 infiltration.

Odeyemi IB (1981). A review of the orogenic events in the Basement Complex of Nigeria, West Africa. Geol Rundsch 70(3):897–909

Odeyemi, I.B., (1988). Lithostratigraphy and structural relationships of the Upper Precambrian metasediments in Igarra area, southwestern Nigeria. In: Oluyide PO, Mbonu WC, Ogezi AEO, Egbuniwe IG, Ajibade AC, Umeji AC (eds) Precambrian geology of Nigeria. Geological Survey of Nigeria, Kaduna, pp 111–125.

Ogunyele, A.C., Obaje, S.O., Akingboye, A.S., Adeola, A.O., Babalola, A.O., Olufunmilayo, A.T. (2020). Petrography and geochemistry of Neoproterozoic charnockite–granite association and metasedimentary rocks around Okpella, southwestern Nigeria. Arab J Geosci 13, 780.

Ogunyele, A.C., Obaje, S.O., Akingboye, A.S., Adeola, A.O., Babalola, A.O., Olufunmilayo, A.T. (2020). Petrography and geochemistry of Neoproterozoic charnockite–granite association and metasedimentary rocks around Okpella, southwestern Nigeria. Arabian Journal of Geosciences 13:780. https://doi.org/10.1007/s12517-020-05785-x

Okeke PO, Meju MA (1985). Chemical evidence for the sedimentary origin of Igarra supracrustal rocks, S.W. Nigeria. J Mining Geol 22:97–104

Okonkwo CT, Ganev VY (2015). Geochemistry and geochronology of orthogneisses in Bode Saadu area, southwestern Nigeria and their implications for the Palaeoproterozoic evolution of the area. J Afr Earth Sci 109:131–142. https://doi.org/10.1016/j.jafrearsci.2015.05.012.

Olarewaju VO (1999). Fluid inclusion studies of coarse-grained charnockitic and the hybrid rocks in Ukpilla area, southwestern Nigeria. J Min Geol 35(1):1–7.

Olarewaju, O. (2006). Charnockites of the Nigerian Basement: Petrology and Tectonic Implications. In: Geology and Mineral Resources of Nigeria. Lecture Notes in Earth Sciences, vol 120. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-540-92685-6_2

Olobaniyi SB, Annor AE (2003). Petrology and age implication of ultramafic schist in the Isanlu area of the Isanlu-Egbe Schist Belt, southwestern Nigeria. J Min Geol 39:1–9

Omitogun AA, Caby R, Debat P (1991). Le métamorphism Pan-African de la partie centrale de la zone mobile du Nigéria. Comptes Rendus de l'Académie de Science, Paris 313(2):1417–1423

Oyeshomo, A.V., Bolarinwa, A.T., Altenberger, U., Harlov, D.E.,

Olayemi, S.O., Ajila, T.F. (2025). Mineral chemistry and P-T conditions of incipient charnockite around Ikare, southwestern Nigeria. Discovery Nature 2, e1dn1039. https://doi.org/10.54905/disssi.v2i3.e1dn1039. https://doi.org/10.1007/s12517-020-05785-x

Oziegbe, E.J. (2023). Petrographic interpretation of charnockitic rocks from the southwestern Nigeria Basement Complex. Development Journal of Science and Technology Research (DJOSTER), Vol. 12, No. 2.

Rahaman MA (1988). Recent advances in the study of the Basement Complex of Nigeria. In: Oluyide PO, Mbonu WC, Ogezi AEO, Egbuniwe IG, Ajibade AC, Umeji AC (eds) Precambrian geology of Nigeria. Geological Survey of Nigeria, Kaduna, pp 11–43.

Rahaman, M.A., Ajayi, T.R., Oshin, I.O., Asubiojo, F.O.I., (1988). Trace element geochemistry and tectonic setting of Ile-Ife schist belt. In: Oluyide PO, Mbonu WC, Ogezi AEO, Egbuniwe IG, Ajibade AC, Umeji AC (eds) Precambrian geology of Nigeria. Geological Survey of Nigeria, Kaduna, pp 241–256

Rahaman, MA, Tubosun IA, Lancellot JR (1991). U-Pb geochronology of potassium syenites from southwestern Nigeria and timing of deformation events during the orogeny. J Afr Earth Sci 13(3–4):387–395

Reyment, R. A. (1965). Aspects of the Geology of Nigeria: The Stratigraphy of the Cretaceous and Cenozoic Deposits. Ibadan University Press, 145p.

Sarkar, S., Bose, S., *et al.*, (2023). Petrological, geochemical, and geochronological evolution of massif-type charnockite from the Eastern Ghats Province, India: Implications for the regional tectonics of the Rayner–Eastern Ghats orogeny. Precambrian Research, 387, 106994. https://doi.org/10.1016/j.precamres.2023.106994

Streckeisen, A.L., (1976). To each plutonic rock its proper name. Earth Sci Rev 11:1–12

Tubosun, I.A., Lancelot, J.R., Rahaman, M.A., Ocan, O.O., (1984). U-Pb Pan-African ages of two charnockite-granite association from southwestern Nigeria. Contrib Miner Petrol 88:188–195.

Turner DC (1983). Upper Proterozoic schist belts in the Nigerian sector of the Pan-African province of West Africa. Precambrian Res 21:55–79.

Uzoegbu, U.M., Dike, E.F.C., Obaje, N.G., Uchebo, U.A. (2013). The Unusual microscopic features in coal and characterization of coals from the Anambra basin, Nigeria. Jour. Sci. Tech. Res., 12(2), 11-25.

Waldron K, Parsons I, Brown WL. (1993). Solution-redeposition and the orthoclase-microcline transformation: evidence from granulites and relevance to 18O exchange. Mineralogical Magazine. 57 (389):687-695. doi:10.1180/minmag.1993.057.389.13

Woakes M, Rahaman MA, Ajibade AC (1987). Some metallogenetic features of the Nigerian Basement. J Afr Earth Sci 6(5):655–664.

Yang, H., and Yao, J. (2024). Generation of the charnockite by residua entrainment in water-deficient melts: insights from minerals mineral composition, and H2O-in-zircon, EGU General Assembly 2024, Vienna, Austria, 14–19 Apr 2024, EGU24-2231, https://doi.org/10.5194/egusphere-egu24-2231, 2024.

Yang, H., Yao, J., Cawood, P. A., Zhao, G., Han, Y., Li, X., *et al.* (2025). Quantifying magma water contents: A new entrainment model for charnockite formation. Journal of Geophysical Research: Solid Earth, 130, e2024JB029753. https://doi.org/10.1029/2024JB029753