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Major oxide geochemistry and petrogenetic implications of Pan-African rocks around Omi-Olori, Ado-Ekiti Area, Southwestern, Nigeria

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Abstract **Original Research Article**

This study presents whole-rock major oxide geochemical data for selected Pan-African basement rocks from the Omi-Olori area, Ado–Ekiti, southwestern Nigeria, with the aim of constraining their petrogenesis, magma evolution, and tectonic setting. The investigated lithologies include biotite granite, leucogranite, and granitic gneiss, diorite, and charnockitic rocks. The geochemical results reveal silica-rich granitoids (SiO_2, 67–72 wt.%) contrasted with intermediate to mafic compositions in dioritic and charnockitic rocks (SiO_2, 50–59 wt.%). Harker variation trends indicate systematic decreases in Fe_2O_3, MgO, CaO, and TiO_2 with increasing SiO_2, suggesting fractional crystallization as a dominant magmatic process. Alumina saturation indices (A/NK) vs (A/CNK) show that the granitoids are predominantly peraluminous to weakly metaluminous, indicating significant crustal contributions, whereas the diorites and charnockitic rocks exhibit near-metaluminous signatures, reflecting mantle influence. The AFM diagram defines a calc-alkaline trend, consistent with magmatism in a convergent to collisional tectonic setting. Petrogenetically, the rocks represent a genetically related suite involving mantle-derived dioritic magmas, crustal anatexis producing granites and leucogranites, and high-temperature deep crustal processes responsible for charnockitic rocks formation. These features are consistent with magmatic evolution during the Pan-African orogeny. The study provides insights into crust–mantle interaction and contributes to the understanding of basement evolution within the Nigerian segment of the Trans-Saharan Belt.

Keywords: Pan African orogeny, basement complex, major oxides, petrogenesis, Ado–Ekiti.

Introduction

The Precambrian Basement Complex of southwestern Nigeria constitutes an integral segment of the Pan-African mobile belt, which formed during the Neoproterozoic (±600 Ma) as a result of the collision between the West African Craton and the Congo Craton (Ajibade, 1982; Ajibade *et al.*, 1987 & Dada, 2006). This orogenic event led to widespread crustal deformation, high-grade metamorphism, and extensive magmatism, producing a complex assemblage of migmatite–gneiss complexes, schist belts, and granitoids (Dada, 2006; Akintola, 2024).

The Nigerian Basement Complex records multiple tectonothermal episodes, making it an important region for understanding crustal evolution in West Africa (Dada, 2006; Olaolorun and Akintola, 2018). Among the dominant lithologies are granitic rocks of varying compositions, including biotite granites, leucogranites, and granitic gneisses, alongside intermediate to mafic intrusions such as diorites and charnockitic rocks. These rocks preserve geochemical signatures that reflect their sources, magmatic evolution, and tectonic environment (Dada, 2006).

Major element geochemistry plays a crucial role in petrogenetic studies, as it provides insight into magma differentiation processes such as fractional crystallization, partial melting, and crustal contamination (Akintola, 2024). Additionally, geochemical classification diagrams such as Harker plots, Total alkali-silica (TAS), and alumina saturation indices (A/NK versus A/CNK) are widely used to constrain magma evolution trends and tectonic settings. (Irvine, and Barager 1971; Garrels, and Mackenzie, 1971; Honkamo, 1987).

This study focuses on the Omi-Olori area in Ado–Ekiti, where diverse Pan-African lithologies are well exposed. By integrating field observations with major oxide geochemistry, this work aims to (i) classify the rock types, (ii) evaluate magma evolution processes, and (iii) infer the tectonic setting of emplacement of rocks around Omi-Olori in Ado–Ekiti. The results contribute to a broader understanding of the Pan-African basement evolution in southwestern Nigeria.

Geological Setting

The study area, Omi-Olori in Ado–Ekiti, lies within the southwestern Nigerian Basement Complex, which forms part of the Pan-African mobile belt. This belt developed during the Neoproterozoic (600 ± 50 Ma) as a result of the collision between the West African Craton and the Congo Craton (Rahaman, 1976, 1988; Ajibade *et al.*, 1987; Dada, 2006; Obaje, 2009). The region is characterized by a polycyclic geological history involving multiple phases of deformation, metamorphism, and magmatism (Jones and Hockey, 1964; Oyinloye, 2007; Akintola, 2011; Olaolorun, and Akintola, 2018). The Nigerian Basement Complex is typically subdivided into three major lithological units: (i) the migmatite–gneiss complex, (ii) the schist belts, and (iii) the Pan-African granitoids (Older Granites).

The Omi-Olori area is dominated by crystalline basement rocks, including quartzites, gneisses, charnockitic rocks, diorites, biotite granites, and leucogranites. These lithologies represent different stages of crustal evolution and are largely associated with Pan-African tectonothermal events (Akintola, 2011). These lithologies intrude older migmatitic gneisses and are generally attributed to Pan-African magmatism. (Dada, 2006).

Materials and Methods

Representative rock samples were systematically collected from fresh and unweathered outcrops across the Omi-Olori area, Ado–Ekiti, southwestern Nigeria. Care was taken to ensure that the samples were spatially distributed and representative of the major lithological units, including biotite granite, leucogranite, granitic gneiss, diorite, and charnockitic rocks. Weathered surfaces were removed prior to sampling to minimize contamination. The collected samples were prepared following standard geochemical procedures. Each sample was crushed, pulverized, and homogenized using an agate mill to avoid metal contamination. Whole-rock major oxide compositions were determined using X-ray fluorescence (XRF) spectrometry. The analysis was carried out on fused glass beads prepared using lithium tetraborate ($Li_2B_4O_7$) flux, a method widely adopted for major element analysis due to its ability to produce homogeneous samples and minimize matrix effects (Irvine and Baragar, 1971; Rollinson, 1993).

Analytical precision for major oxides is estimated to be better than ±2%, based on repeated measurements of international rock standards. Loss on ignition (LOI) was determined by heating powdered samples to approximately 1000°C to account for volatile components, following standard procedures in whole-rock geochemistry (Rollinson, 1993).

The resulting geochemical dataset was used for classification and petrogenetic interpretation of the rocks. Major element data were evaluated using established geochemical discrimination tools, including Harker variation diagrams, Total Alkali–Silica (TAS) classification, alumina saturation indices (A/NK versus A/CNK), and AFM ternary plots (Shand, 1943; Irvine and Baragar, 1971). These methods are widely applied in igneous petrology to constrain magma evolution processes such as fractional crystallization, partial melting, and crustal contamination (Rollinson, 1993; Winter, 2010).

Results

Field relationship and local geology of the area of Omi-Olori Area, Ado-Ekiti.

Field relationships indicate multiple intrusive phases, with granitoids forming extensive plutons and charnockitic rocks occurring as discrete bodies. The rocks display variable textures ranging from coarse-grained equigranular granites to foliated granitic gneisses and massive charnockitic rocks. The granitic gneisses are among the oldest lithologies and are typically medium- to coarse-grained, strongly foliated, and exhibit well-developed gneissic banding. These rocks are interpreted as metamorphosed equivalents of older granitoids or sedimentary protoliths subjected to high-grade metamorphism (Akintola, 2011).

Charnockitic rocks occur as massive, coarse-grained bodies and are characterized by the presence of orthopyroxene (hypersthene), indicating high-temperature formation under granulite facies conditions. These rocks likely represent deep crustal magmatic intrusions or metamorphic transformations of pre-existing rocks under anhydrous conditions.

The diorites in the area occur as small to medium intrusive bodies within gneissic and charnockitic units and are generally less deformed. They are typically coarse-grained, composed of plagioclase, hornblende, and minor biotite, and are less deformed than surrounding gneisses. Field evidence suggests that diorites are syntectonic or late-tectonic stages of the Pan-African orogeny, cutting across foliation planes of the older gneisses.

Biotite granites are widespread and typically intrude both gneisses and diorites. They are medium- to coarse-grained and may show weak foliation, indicating emplacement during the late stages of deformation. These granites are interpreted as products of crustal melting and magmatic differentiation. Leucogranites represent the youngest intrusive phase and occur as dykes and small plutons cutting across older lithologies. Their light color and low mafic mineral content indicate highly evolved magmas, likely formed during the final stages of the Pan-African magmatic cycle.

On the metamorphism, the geological relationships of rocks in the area indicate a progressive evolution from high-grade metamorphic rocks (charnockitic and gneisses) to syn-tectonic intrusions (diorites), followed by late-to post-tectonic granitoids (biotite granites and leucogranites), reflecting the tectonomagmatic evolution of the region (Akintola, 2011).

The geological map of the Omi-Olori area illustrates the spatial distribution of major lithological units and their structural relationships. The map reveals a heterogeneous assemblage ranging from Precambrian to Pan-African rocks within the basement rocks which are dominated by charnockitic bodies and granitic gneisses, which form the older basement framework in Figure 1. The lithologies observed include leucogranites, biotite granites, diorites, granitic gneisses, and charnockitic rocks, each showing distinct textural, structural, and compositional characteristics. Charnockitic rocks occupy significant portions of the area and are typically massive, although locally foliated. They display high-grade metamorphic textures, including granoblastic textures with well-developed foliation in places. Field relationships suggest that charnockitic rocks represent some of the older basement units, often intruded by granitic and dioritic magmas along fractures and foliation planes. The granitic gneisses occur as elongated bodies with well-developed foliation trends, reflecting regional deformation. Dioritic intrusions are observed as smaller bodies cutting across the gneissic fabric, indicating their younger age. The granitic gneisses are medium- to coarse-grained, foliated rocks, commonly exhibiting gneissic banding with alternating quartz-feldspar-rich and biotite-rich layers.

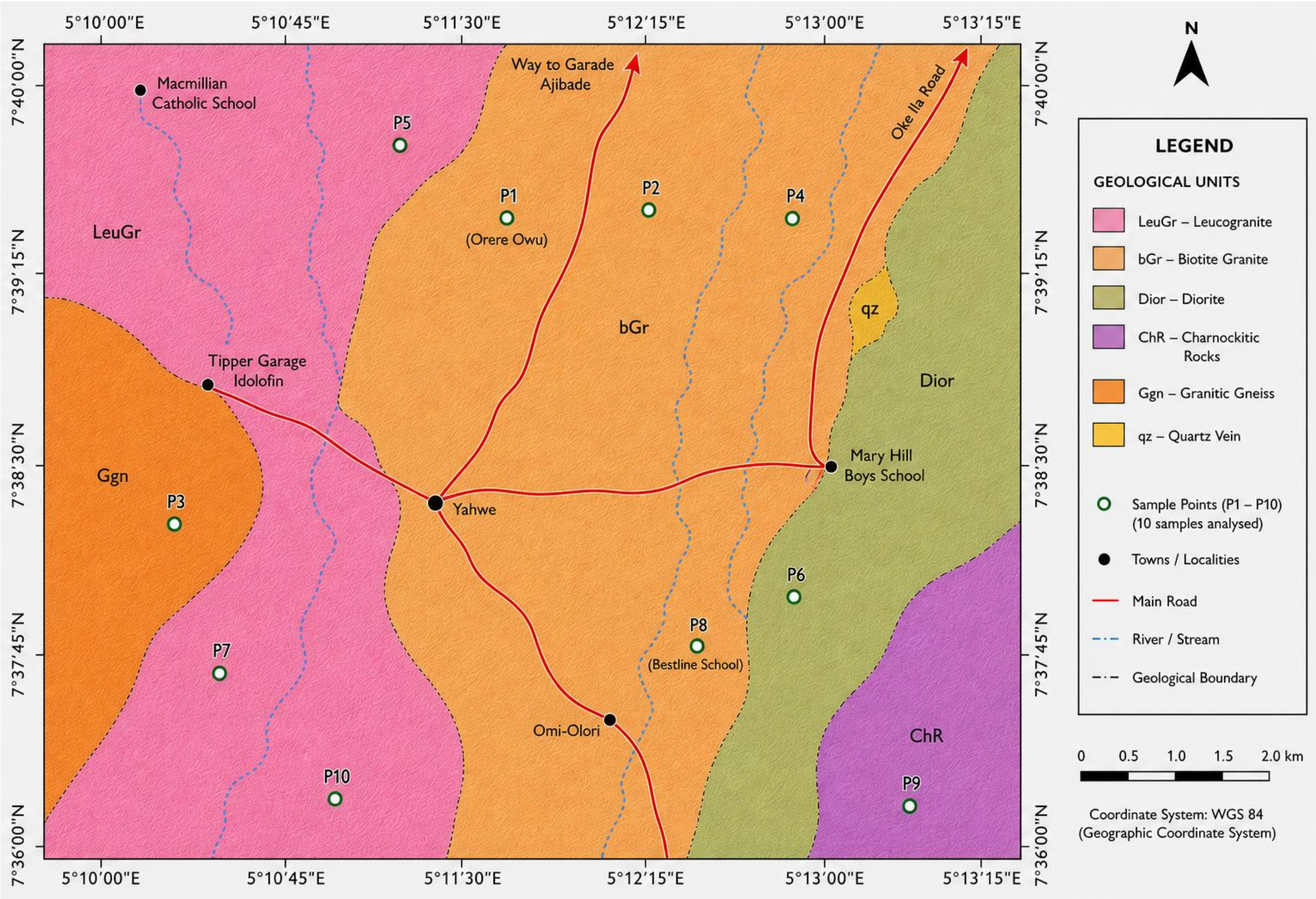


Figure 1: Geological map of the study area

These rocks are interpreted as metamorphosed older granitic bodies, possibly of the Archean-Proterozoic basement. Contact relationships show that granitic gneisses are sometimes intruded by diorites and biotite granites, indicating a younger emplacement relative to the granitic gneisses.

Biotite granites are widespread, medium- to coarse-grained, and contain conspicuous biotite flakes, giving the rocks a foliated to weakly foliated appearance in places. These granites often intrude granitic gneisses and diorites, showing sharp, non-foliated contacts. They represent post-tectonic or late-stage Pan-African granitic intrusions, reflecting the evolution of magmatism in the area. Leucogranites are the youngest intrusive rocks in the area, typically light-colored, fine- to medium-grained, and almost devoid of mafic minerals. They are observed as dykes and small intrusive bodies cutting through biotite granites and gneisses, commonly aligned along fractures and shear zones, highlighting structural during their emplacement. Their emplacement marks the final phase of magmatism, likely associated with the waning stages of the Pan-African orogeny.

The structural pattern of the area is defined by foliations, lineations, and fractures, which generally trend in a consistent direction, reflecting the regional tectonic stress regime (Honkamo, 1987). The cross-cutting relationships observed on the map confirm the relative age sequence: Charnockitic rock→granitic gneiss→diorite →biotite granite→ Leucogranite. The geological map of Omi-Olori area therefore provides strong field evidence for multiple intrusive phases and progressive magmatic evolution associated with the Pan-African orogeny.

Intrusive relationships and structural observations

Diorites cut across older gneisses and charnockitics rock. The biotite granites intrude both gneisses and diorites. Leucogranites are the youngest, intruding biotite granites and following shear zones. Foliation and lineation are pronounced in granitic gneisses and charnockitic rocks, indicating high-grade metamorphism and deformation. Diorites and granites display less deformation, suggesting post-tectonic emplacement. Leucogranite dykes exploit fractures and shear zones, highlighting late-stage brittle tectonics.

Major Oxide Geochemistry and classification of rocks in the study area

The major oxide compositions of the investigated rocks are summarized in Tables 1 and 2. The contents of SiO_2 contents range from 49.9 wt.% in diorites to 71.7 wt.% in leucogranites; as of Al_2O_3 values (13–18 wt.%) are relatively high in granites and granitic gneisses, reflecting feldspar abundance. Fe_2O_3, MgO, CaO, and TiO_2 are enriched in diorites and charnockitic rocks, consistent with higher proportions of mafic minerals. On the basis of SiO_2 and alkali contents, the rocks classify into granitoids (biotite granite, leucogranite, granitic gneiss), intermediate diorites, and charnockitic rocks.

Table 1: Major elements composition of rocks from Omi-olori area (wt.%)

Samples	**1 BiotiteGranite**	**2 Biotite Granite**	**3 Granitic gneiss**	**4 Biotite Granite**	**5 Leucogranite**	**7 Leucogranite**	**10 Leucogranite**	**6 Diorite**	**8 Diorite**	**9 Charnockitic Rocks**	**MEAN**
Oxides (%) **SiO_2**	69.39	69.71	67.53	69.08	71.74	71.16	71.49	51.37	49.86	58.79	65.39
Al_2O_3	14.72	14.77	17.6	14.73	13.11	14.58	14.53	14.44	15.49	16.18	15.01
Fe_2O_3	3.64	3.6	2.35	3.97	3.95	3.51	3.19	3.31	13.16	9.18	4.986
MnO	0.05	0.05	0.03	0.05	0.06	0.04	0.02	0.21	0.17	0.17	0.085
MgO	0.36	0.39	0.29	0.36	0.38	0.36	0.28	4.95	4.83	1.02	1.322
CaO	2.05	2.24	3.14	2.08	2.11	0.96	0.69	7.82	7.98	4.64	3.371
Na_2O	3.35	3.28	5.06	3.3	3.02	3.42	3.32	3.41	3.35	3.87	3.538
K_2O	5.71	5.58	3.55	5.89	4.89	5.6	5.86	1.39	1.72	4.59	4.478
TiO_2	0.6	0.51	0.31	0.49	0.48	0.41	0.36	2.28	2.56	1.18	0.928
P_2O_5	0.34	0.22	0.12	0.17	0.17	0.12	0.11	0.8	0.75	0.49	0.329
Cr_2O_3	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	0.01	0.01	Bdl	Bdl
L.O.I	0.19	0.35	0.87	0.35	0.3	0.42	0.46	0.7	0.52	0.04	0.42
Total	100.4	100.69	100.83	100.46	100.2	100.56	100.31	100.70	100.72	100.14	100.50

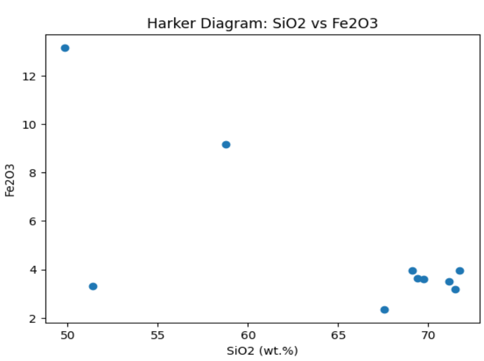
Table 2. Range of major oxide compositions (wt.%) of rocks around Ado–Ekiti

Oxide	**Biotite Granite**	**Granitic Gneiss**	**Leucogranite**	**Diorite**	**Charnockitic Rock**
SiO_2	67–70	~68	71–72	49–51	~59
Al_2O_3	14–18	~17	13–15	14–15	~16
Fe_2O_3	2–4	~2	3–4	13	~9
MgO	<	< 0.5	< 0.5	~5	~1
CaO	1–3	~3	<2	~8	~5
Na_2O	3–5	~5	3–4	~3	~4
K_2O	4–6	~4	5–6	<2	~5

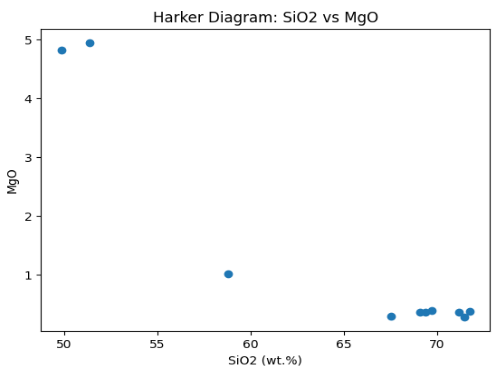
The discriminant plots of rocks in the area: Harker variation diagrams, Total alkali–silica (TAS), and A/CN versus A/CNK.

The Harker variation diagrams (SiO_2 vs. Fe_2O_3, MgO, CaO, and K_2O) illustrating fractional crystallization trends Figures 2 a-d. The concentrations of Fe_2O_3, MgO, CaO decrease with increasing SiO_2, K_2O increases slightly with SiO_2 in Figure 2 a-d. These trends clearly indicate fractional crystallization. The early removal of ferromagnesian minerals (biotite, amphibole, pyroxene) this results to lowers Fe_2O_3 and MgO. Plagioclase feldspar → lowers CaO. The enrichment of K_2O suggests, Late-stage potassic differentiation that result to Formation of leucogranites. The magma evolved from mafic/intermediate (dioritic) to felsic granitic /leucogranitic) compositions.

The studied rocks are predominantly peraluminous, particularly the granitic rocks (granitoids) (biotite granites and leucogranites), which show A/NK versus A/CNK values (after Shand, 1943), significantly greater than is shown in 1 Figure 3. However, the dioritic and charnockitic samples display lower A/NK versus A/CNK values, indicating weakly peraluminous to near-metaluminous compositions. This variation suggests that while the granitoids are largely crust-derived, the intermediate rocks may have originated from more mantle-influenced magmas with limited crustal contamination. The AFM (Na_2O + K_2O–Fe_2O_3–MgO) diagram for rocks of the Omi-Olori area (Fgure 4). The samples define a calc-alkaline trend after Irvine and Baragar (1971), with diorites plotting towards the MgO–Fe_2O_3 field, granitoids clustering near the alkali apex, and charnockitic rocks occupying an intermediate position.



(a)



(b)

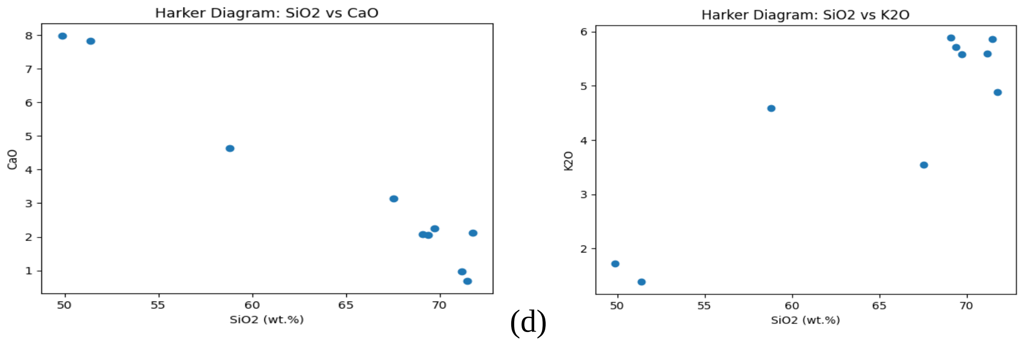


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Fig (2) Harker Variation Diagrams (a) (SiO_2 vs Fe_2O_3, b) (SiO_2 vs MgO, c) (SiO_2 vs CaO, d) (SiO_2 vs K_2O)

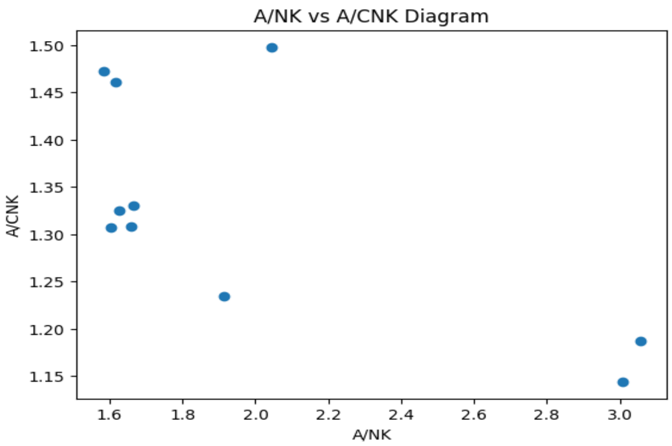

Fig 3: Al_2O_3–(Na_2O+K_2O) A/NK Versus A/CNK. Al_2O_3–(CaO+Na_2O+K_2O) discrimination plot illustrating peraluminous to metaluminous character (after Shand, 1943).

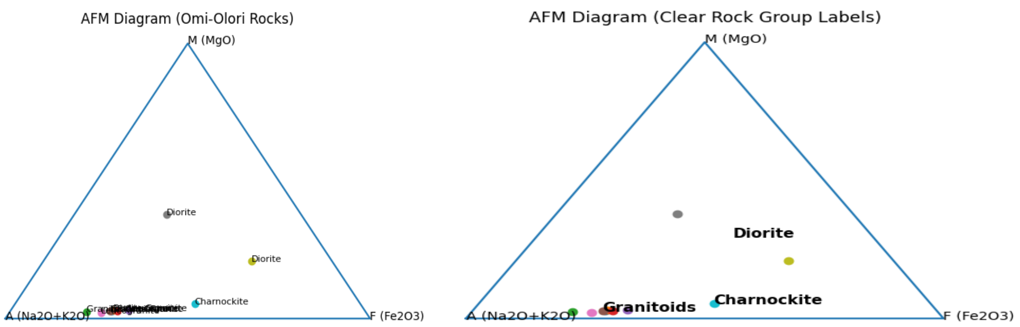

Fig. 4: The AFM diagram of (Na_2O + K_2O–Fe_2O_3–MgO) after Irvine and Baragar (1971) showing the granitoids (granites, leucogranites with gneiss tightly clustered near A (Na_2O + K_2O); diorites → shifted toward M–F field (more primitive) and Charnockite → intermediate position between F and A.

Discussion

Magma Evolution and fractionation; tectonic implications and petrogenesis

Hacker binary plots show a Systematic decreases in concentrations of Fe_2O_3, MgO, CaO, and TiO_2 with increasing SiO_2 suggest fractional crystallization involving mafic minerals (biotite, amphibole, pyroxene) and plagioclase (Figures 2a-d). The granitoids represent evolved melts derived from more mafic parental magmas or partial melting of crustal sources. The relatively high Al_2O_3 contents and elevated K_2O in the granitoids suggest peraluminous to weakly metaluminous compositions, typical of crust-derived or crustally contaminated magmas (Figure 3). This is consistent with Pan-African syn- to late-tectonic granites widely reported in southwestern Nigeria. The calc-alkaline signature and compositional range from diorite to granite support emplacement in a convergent-margin to collisional tectonic setting during the Pan-African orogeny. Charnockitic rocks likely represent deeper-seated, high-temperature magmas or dehydrated granulite-facies equivalents of granitoids. The granitoids, diorites, and charnockitic rocks of the Omi-Olori area collectively define a genetically related magmatic suite that reflects crust–mantle interaction during the Pan-African orogeny. The samples on AFM ternary plot (Figure 4) define a calc-alkaline trend for rocks of the Omi-Olori area, with diorites plotting towards the MgO–Fe_2O_3 field, granitoids clustering near the alkali apex, and charnockitic rocks occupying an intermediate position.

The origin of rocks in Omi-Olori area can be basically grouped into three:

1. Mantle Contribution: Origin of Diorites the dioritic rocks represent the least evolved members of the suite and are interpreted as products of mantle-derived magmas as I-type Magmatism, characterized with moderate SiO_2 and relatively high MgO, Fe_2O_3, and CaO, weakly peraluminous to near-metaluminous character. These features indicate: partial melting of the upper mantle; and possible modification in a subduction-related setting (Ekwueme, 1991).

2. Crustal Anatexis: Formation of Granites (S-type / Crust-Influenced). The granitic rocks (biotite granites and leucogranites) represent evolved melts derived mainly from the continental crust, characterized with high SiO_2 and K_2O and strongly peraluminous (A/CNK > 1), enrichment in alkalis and depletion in Fe–Mg. These features indicate: Partial melting of metasedimentary or felsic crust; significant crustal reworking and advanced fractional crystallization. The leucogranites represent the final stage melts, formed through: extreme differentiation melt segregation along shear zones.

3. Deep Crustal Processes: Origin of Charnockitic rocks: Charnockitic rocks represent high-temperature, deep crustal magmatism or metamorphism, characterized with the presence of orthopyroxene (hypersthene). These indicate that the rocks were formed under granulite facies conditions characterized with High (temperature), low water activity, influence by either as dehydration melting of lower crust, OR transformation of pre-existing rocks under dry conditions. They represent the deep crustal equivalent of the magmatic system.

The petrogenesis of the Omi-Olori rocks reflects a coupled crust–mantle magmatic system in which mantle-derived dioritic magmas provided the thermal and material input necessary for crustal melting (Glickson, 1967; Hallberg, 1972). This led to the generation of peraluminous granitic and leucogranitic magmas through anatexis and fractional crystallization. The associated charnockitic rocks represent high-temperature processes within the lower crust, possibly linked to dehydration melting or granulite facies metamorphism. Together, these lithologies define a coherent calc-alkaline magmatic suite emplaced during the Pan-African orogeny, recording a transition from mantle-dominated magmatism to crustal reworking in a collisional tectonic environment.

Conclusions

The granitoids (biotite granites and leucogranites), diorites, and charnockitic rocks of the Omi-Olori area collectively define a genetically related magmatic suite that reflects crust–mantle interaction during the Pan-African orogeny. The Omi Olori area shows a typical southwestern Nigerian basement complex evolution, where old high-grade charnockitic rocks and granitic gneisses were intruded by syn-tectonic diorites, followed by post-tectonic biotite granites and finally leucogranites. This sequence reflects the progressive Pan-African magmatic and metamorphic events in the region. The major oxide geochemistry of Pan-African basement rocks around Ado–Ekiti reveals a compositional spectrum from dioritic to highly evolved granitic rocks. The data indicate calc-alkaline affinity, significant fractional crystallization, and strong crustal influence on magma genesis. These characteristics are consistent with Pan-African collisional tectonics and contribute to regional models of basement evolution in southwestern Nigeria m .

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