Petrochemistry and petrogenesis of the Precambrian Basement Complex rocks around Akungba-Akoko, southwestern Nigeria

Petrokemija in petrogeneza predkambrijskih kamnin podlage na območju Akungba-Akoko, JZ Nigerij

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Abstract

Field, mineralogical and petrochemical studies of the Precambrian Basement Complex rocks around Akungba-Akoko were carried out with the aim of determining their petrology, petrochemical characteristics and petrogenesis. The petrology of Akungba-Akoko area comprises migmatite, granite gneiss and biotite gneiss intruded by biotite granite, charnockite and minor felsic and basic rocks. Seventeen representative samples of the granite gneiss, biotite gneiss, biotite granite and charnockite were collected during field geological mapping of the area for petrographic and geochemical analyses. Modal mineralogy revealed that the granite gneiss, biotite gneiss and granite have assemblages of quartz + feldspar + mica $\pm$ hornblende + opaques and are granitic in composition. The charnockite is characterized by anhydrous mineral assemblage of quartz + feldspar + biotite + hornblende + pyroxene + opaques. Petrochemical data of the rocks revealed that they are moderately to highly enrich in SiO_2 , sub-alkaline, peraluminous, magnesian to ferroan and calcic and have $\text{K/Rb} < 283$. The geochemical characteristics and discrimination of the rocks indicated that the granite gneiss and biotite gneiss are orthogneisses formed by metamorphism of igneous protoliths of granitic composition and the biotite granite and charnockite are of igneous/magmatic origin. The biotite granite, charnockite and the igneous protoliths of the biotite gneiss are I-type granitoids formed from crustal igneous-sourced melt(s), while the igneous protoliths of the granite gneiss is a S-type granitoid probably derived

Povzetek

Z namenom določitve petrologije, petrokemičnih značilnosti in petrogeneze so bile na območju Akungba-Akoko izvedene terenske, mineraloške in petrokemične raziskave predkambrijskih kamnin podlage. Petrologijo območja Akungba-Akoko sestavljajo migmatit, granitni gnajns in biotitni gnajns, intrudirani z biotitnim granitom, charnokitom in manjšimi felsičnimi in bazičnimi kamninami. Med terenskim geološkim kartiranjem območja je bilo zbranih sedemnajst reprezentativnih vzorcev granitnega gnajnsa, biotitnega gnajnsa, biotitnega granita in charnokita za petrografske in geokemične analize. Modalne mineraloške preiskave so pokazale da granitni gnajns, biotitni gnajns in granit vsebujejo kremen + glinence + sljudo $\pm$ rogovačo + neprozorne minerale in so granitni v kompoziciji. Charnokit je karakteriziran kot nehidriran mineral sestavljen iz kremena + glinavca + biotita + rogovače + piroksena + neprozornega minerala. Petrokemični podatki kamnin kažejo, da so srednje do visoko bogate z SiO_2 , sub-alkalne, peraluminaste, magnezijske do železove, kalcijske in imajo razmerje $\text{K/Rb} < 283$. Geokemične karakteristike in diskriminacije kamnin kažejo, da so granitni gnajnsi in biotitni gnajnsi ortognejsi, nastali s preobrazbo magmatskih protolitov granitne kompozicije in da so biotitni graniti in charnokiti magmatskega nastanka. Biotitni granit, charnokit in magmatski protoliti biotitnih gnajnsov so granitoidi I-tipa, nastali s taljenjem skorje, medtem ko so magmatski protoliti granitnih gnajnsov granitoidi S-tipa, verjetno nastali iz taljenja plitve skorje ali sedimentov. Tektonska diskriminacija kamnin prikazuje, da

from shallow crustal or sedimentary-sourced melt(s). Tectonic discrimination of the rocks indicated that they were formed during a phase of magmatic activity related to collision and subduction.

Keywords: granitoids, mineralogy, orthogneisses, petrogenesis, petrochemistry

so nastale med stopnjo vulkanske aktivnosti povezane s trkom in subdukcijo.

Ključne besede: granitoidi, mineralogija, ortognejsi, petrogeneza, petrokemija

Introduction

The Precambrian Basement Complex rocks of Akungba-Akoko area form a part of the southwestern Nigerian Basement Complex (Figure 1). The Nigerian Basement Complex lies within the reactivated Pan-African mobile belt extending between the West African Craton in the west and the Congo Craton in the south-east [1, 2]. It comprises three major lithological units: the Migmatite–Gneiss Complex, the Schist Belts and the Older Granites, which intrude the former two units [3].

The petrology, mineralogy, geochemical characteristics, structure, petrogenesis (origin) and other features of the Basement Complex

rocks of Nigeria, particularly the Schist Belts, have been studied to considerable details by several researchers [4–10]. However, there are still more work to be done, particularly on the Migmatite–Gneiss Complex and the Pan-African granitoids (Older Granite suite and charnockitic rocks), in order to determine their petrogenesis (origin) and possible evolutionary models, tectonics, ages and correlation with similar rock groups in other parts of the world [1, 11, 12]. In view of the above, this paper presents field, mineralogical and petrochemical data of the Migmatite–Gneiss Complex rocks and granitoids around Akungba-Akoko and discusses their petrology, mineralogy and petrochemical characteristics and petrogenesis.

Figure 1: (a) Regional geological map of Nigeria within the Pan-African mobile belt between the West African and Congo Cratons and (b) outline geological map of Nigeria showing Akungba-Akoko in the southwestern Nigerian Basement Complex (modified after [3]).

Methods

Geological mapping of Akungba-Akoko area on a scale of 1:20,000 was carried out to determine the rock types occurring in the area and their structural relationships. Seventeen fresh representative rock samples comprising five granite gneiss, four biotite gneiss, four biotite

granite and four charnockite were collected for petrographic and geochemical analyses. Thin sections of seven samples were prepared and studied, and modal compositions were determined using a transmitted light microscope at the Department of Geology, University of Ibadan, Nigeria. Major and trace element geochemical analyses of ten rock samples were

carried out using the Energy Dispersive X-Ray Fluorescence (ED-XRF) machine (PANalytical model) at the National Geosciences Research Laboratory, Kaduna, Nigeria. The samples were crushed and pulverised to $<63\ \mu\text{m}$. About 15 g of the pulverised samples were used to make glass beads and pressed pellets, which were slotted into the computerised ED-XRF spectrometer for major and trace elemental analyses, respectively. The laboratory results were interpreted using discrimination diagrams to determine their petrochemical characteristics and petrogenesis.

Results and Discussion

Petrology and Mineralogy

The petrology of Akungba-Akoko area comprises mainly Migmatite–Gneiss Complex rocks intruded by Pan-African granitoids (Figure 2). The Migmatite–Gneiss Complex rocks occurring in the area are migmatite, granite gneiss and biotite gneiss. Granite gneiss is the predominant rock type covering more than 85% of the area. The granite gneiss is intruded by biotite granite, which trends NE–SW from the central to the northeastern end of the area. In the north-central part of the area, a core of charnockite and

Figure 2: Geological map and schematic cross-section of Akungba-Akoko area, southwestern Nigeria.

an enclave (large xenolith) of biotite gneiss occur within the granite gneiss. This lithologic association suggests that the charnockite is intrusive into the granite gneiss; hence, it is younger than the latter and the biotite gneiss is proba-

bly older than the granite gneiss. Field photographs and modal compositions of the various lithologies are shown in Figure 3 and Table 1, respectively.

Figure 3: Field photographs showing (a) granite gneiss intruded by pegmatites (folded and faulted), (b) folded biotite gneiss, (c) biotite granite containing massive melanocratic segregations and (d) boulders of charnockite in Akungba-Akoko.

Table 1: Average modal mineralogical compositions of Akungba-Akoko Basement Complex rocks.

Minerals (vol.%)	GGN1b	GGN2b	BGN1b	BGN2b	BG1b	BG2b	Ch1b
Quartz	29.40	26.60	26.40	26.40	25.30	21.40	22.30
K-feldspar	28.60	23.30	21.60	23.40	22.30	18.00	18.30
Plagioclase feldspar	34.50	35.20	31.00	33.20	32.00	28.30	32.30
Biotite	6.10	8.40	10.10	10.20	14.90	25.40	8.40
Hornblende	-	3.30	8.50	5.10	3.20	5.10	6.00
Muscovite	0.90	2.50	1.40	1.20	2.00	1.00	5.30
Opaque	0.60	0.70	0.90	0.60	0.80	0.90	0.40
Pyroxene	-	-	-	-	-	-	7.70
Total	100.10	100.00	99.90	100.10	100.50	100.10	100.70

GGN – granite gneiss, BGN – biotite gneiss, BG – biotite granite, Ch – charnockite.

The granite gneiss of Akungba-Akoko area (Figure 3a) is weakly to moderately foliated, light grey and medium to coarse grained with a megacrystic (blastoporphyrictic to porphyroblastic) fabric. It is composed of alternating bands of light- and dark-coloured minerals,

most of which are folded. The light-coloured bands are quartz and feldspar rich, while the dark-coloured bands are rich in biotite, hornblende and other ferromagnesian minerals. Quartz and feldspar are the porphyroblasts in the gneiss, and they often have an augen

Figure 4: QAP diagrams for classifying (a) the gneisses and biotite granite (after [14]) and (b) charnockite (after [15]) of Akungba-Akoko.

(eye-like) shape. The granite gneiss, in some locations, contains garnets and quartzitic inclusions. The rock mainly trends WNW-ESE to ENE-WSW with moderate to steep dips to the south. Pegmatites, vein quartz, quartz lenses, basic dykes and sills are abundant in the granite gneiss, sometimes giving the gneiss a migmatitic appearance.

Biotite gneiss occurs in the northern part of the area forming mountains/ridges, which extends northwards to Ikare-Akoko area and beyond. [5, 13] referred to this rock as grey gneiss. The rock is composed essentially of quartz, feldspar and biotite (Table 1) and is dark grey, medium grained and strongly foliated with thin alternating bands of light- and dark-coloured minerals (Figure 3b). A ridge of migmatite composed of granite gneiss, biotite gneiss, granite, aplite, pegmatite and vein quartz extends from the southwestern part of Akungba to Supare-Akoko area in the ENE-WSW direction. The rock is highly deformed with the component rocks being intricately mixed and folded. Ptygmatic folds, faults and joints trending in different directions are abundant in this rock.

The biotite granite intruding granite gneiss in Akungba-Akoko is very rich in biotite and hornblende giving it a very dark colour. The granite

is medium to coarse grained; rich in quartz, feldspar, biotite and hornblende (Table 1) and contains massive melanocratic segregations of biotite, hornblende and iron (Figure 3c). The coarse-grained, dark-coloured charnockite (Figure 3d) with a shining appearance occurring in the granite gneiss is pyroxene-bearing (Table 1) and rich in quartz, feldspar, biotite and muscovite. The charnockite occurs as boulders, some of which are weathered. Minor rocks occurring in the area include pegmatite, vein quartz, aplite, and basic dykes and sills are often found as intrusives within the gneisses and migmatite. The QAP diagrams of [14, 15] revealed that the granite gneiss, biotite gneiss and biotite granite are granitic in composition (Figure 4a) and the charnockite is a true charnockite (Figure 4b).

Petrochemistry and Petrogenesis

Petrochemical data of the basement rocks around Akungba-Akoko (Tables 2 and 3) revealed that the rocks have moderate to high SiO_2 contents: granite gneiss (73.86–74.58 wt.%), biotite gneiss (67.80–73.62 wt.%), biotite granite (59.83–60.06 wt.%) and charnockite (57.50–59.70 wt.%). Based on silica contents, the gneisses are classified as acidic rocks, while

Table 2: Major element compositions (in wt.%) of the Basement Complex rocks of Akungba-Akoko.

Major oxides	Granite gneiss			Biotite gneiss		Biotite granite		Charnockite		
	GGN1	GGN2	GGN3	BGN1	BGN2	BG1	BG2	Ch1	Ch2	Ch3
SiO ₂	74.40	73.86	74.58	73.62	67.80	60.06	59.83	57.50	58.72	59.70
TiO ₂	0.18	0.23	0.32	0.50	0.69	1.00	1.03	1.09	0.98	0.88
Al ₂ O ₃	13.40	13.84	13.52	12.60	14.63	16.77	17.04	17.90	16.78	15.20
Fe ₂ O ₃	3.26	3.83	3.68	3.58	5.33	6.66	6.68	6.70	6.68	6.73
MnO	0.03	0.06	0.04	0.05	0.04	0.13	0.15	0.25	0.26	0.13
MgO	0.27	0.32	0.21	0.76	1.00	3.02	2.92	2.41	3.02	3.11
CaO	3.00	2.89	2.04	3.01	4.18	5.54	6.05	7.11	6.93	7.02
Na ₂ O	2.01	1.75	1.80	1.62	2.06	0.84	0.67	0.86	0.72	0.70
K ₂ O	2.40	2.59	3.00	3.63	2.54	2.29	2.39	2.35	2.37	3.03
P ₂ O ₅	ND	ND	ND	ND	ND	ND	ND	0.01	ND	0.01
LOI	0.51	0.58	0.71	0.90	1.40	3.25	3.03	2.86	3.15	2.45
TOTAL	99.46	99.95	99.90	100.27	99.67	99.56	99.79	99.04	99.61	98.96

GGN – granite gneiss, BGN – biotite gneiss, BG – biotite granite, Ch – charnockite.

Table 3: Trace element compositions (in ppm) of the Basement Complex rocks of Akungba-Akoko.

Trace elements	Granite gneiss			Biotite gneiss		Biotite granite		Charnockite		
	GGN1	GGN2	GGN3	BGN1	BGN2	BG1	BG2	Ch1	Ch2	Ch3
Ba	300	470	310	510	240	580	684	815	722	814
Co	5	6	4.9	3	1	3	4	3.8	4	2
Cr	0.38	0.3	0.28	0.2	0.27	1	2	2	2	1
Nb	7	5	4	2	2	1	2	3	3	2
Ni	8	7	6	3	12	6	9	7	5	4
Rb	82	90	122	100	130	120	100	98	120	116
Sc	2	3	3	1	1	1	1	3	1	-
Sr	110	90	116	88	40	138	150	14	167	132
Th	18	12	22	16	24	12	13	12	14	10
V	1	12.5	17	2	3	13.7	13	10	12	16
Y	27	14	32	40	14	31	42	40	38	26
Zr	100	66	80	122	70	119	130	110	120	116
K/Rb	242.89	238.82	204.07	301.25	162.15	158.37	198.34	199.00	163.90	216.77

GGN – granite gneiss, BGN – biotite gneiss, BG – biotite granite, Ch – charnockite.

Figure 5: Petrochemical diagrams for discriminating Akungba-Akoko granite gneiss, biotite gneiss, biotite granite and charnockite. (a) $\text{K}_2\text{O} + \text{Na}_2\text{O}$ versus SiO_2 plot (after [17]), (b) K_2O versus SiO_2 plot (after [18]), (c) $\text{Al}_2\text{O}_3 / (\text{Na}_2\text{O} + \text{K}_2\text{O})$ versus $\text{Al}_2\text{O}_3 / (\text{CaO} + \text{Na}_2\text{O} + \text{K}_2\text{O})$ molecular plot (after [19]), (d) $\text{Al}_2\text{O}_3 / (\text{CaO} + \text{Na}_2\text{O} + \text{K}_2\text{O})$ versus SiO_2 (after [20]), (e) $\text{FeO}_{\text{total}} / (\text{FeO}_{\text{total}} + \text{MgO})$ versus SiO_2 (after [21]) and (f) $\text{K}_2\text{O} + \text{Na}_2\text{O} - \text{CaO}$ versus SiO_2 plot (after [21]).

the biotite granite and charnockite are classified as intermediate rocks. Al_2O_3 in the rocks range from 12.60 to 17.90 wt.%. The moderate to high silica and alumina contents of these

rocks are correlatable with their high quartz and feldspar contents (Table 1). Fe_2O_3 and MgO are relatively higher in the charnockite (Fe_2O_3 : 6.68–6.73 wt.%; MgO: 2.41–3.11 wt.%),

Figure 6: Petrochemical diagrams of (a) TiO_2 versus SiO_2 (after [22]) and (b) Rb versus $\text{Nb} + \text{Y}$ (after [25]) for determining the petrogenesis and tectonic settings of Akungba-Akoko granite gneiss, biotite gneiss, biotite granite and charnockite.

biotite granite (Fe_2O_3 : 6.66–6.68 wt.%; MgO : 2.92–3.02 wt.%) and biotite gneiss (Fe_2O_3 : 3.58–5.33 wt.%; MgO : 0.76–1.00 wt.%) compared to the granite gneiss (Fe_2O_3 : 3.26–3.83 wt.%; MgO : 0.21–0.32 wt.%). This is as a result of the higher amount of mafic minerals (biotite + hornblende + pyroxene + opaques) in the charnockite, biotite granite and biotite gneiss relative to the granite gneiss. CaO is relatively higher than Na_2O and K_2O in almost all the rocks. All the rocks are also characterized by low to moderate Ba and low Cr, Nb and V contents pointing to a felsic to intermediate composition. The average K/Rb ratios of the rocks (granite gneiss: 228.59, biotite gneiss: 231.70, biotite granite: 178.35 and charnockite: 193.22) are less than that of crustal rocks (283) [16], therefore suggesting crustal sources of the rocks.

Geochemical discrimination of the rocks in the area using the $\text{Na}_2\text{O} + \text{K}_2\text{O}$ versus SiO_2 plot [17] revealed that they are sub-alkaline rocks (Figure 5a). On the K_2O versus SiO_2 plot [18], the biotite and granite gneisses are essentially medium-K calc-alkaline rocks, while the biotite granite and charnockite are high-K calc-alkaline rocks (Figure 5b). All the rock samples except one charnockite sample are plotted within the peraluminous field of the $\text{Al}_2\text{O}_3/(\text{Na}_2\text{O} + \text{K}_2\text{O})$ versus $\text{Al}_2\text{O}_3/(\text{CaO} + \text{Na}_2\text{O} + \text{K}_2\text{O})$ molecular plot of [19] (Figure 5c). The $\text{Al}_2\text{O}_3/(\text{CaO} + \text{Na}_2\text{O} + \text{K}_2\text{O})$ versus SiO_2 plot [20] further distinguished the granite gneiss as S-type

peraluminous granitoid and the biotite gneiss, biotite granite and charnockite as I-type peraluminous granitoids (Figure 5d). The biotite and granite gneisses are ferroan, while the biotite granite and charnockite are essentially magnesian (Figure 5e). The magnesian nature of the biotite granite and charnockite is due to low $\text{FeO}_{\text{total}}/(\text{FeO}_{\text{total}} + \text{MgO})$ and SiO_2 relative to the gneisses. All the rocks are calcic as shown by the $\text{K}_2\text{O} + \text{Na}_2\text{O} - \text{CaO}$ versus SiO_2 plot ([21]) (Figure 5f).

The granite gneiss, biotite gneiss, biotite granite and charnockite of the Akungba-Akoko area plot within the igneous field on the TiO_2 versus SiO_2 discrimination diagram [22] (Figure 6a). This suggests that the granite gneiss and biotite gneiss of the area are orthogneisses and are formed by metamorphism of igneous protoliths, and the biotite granite and charnockite are of igneous origin. The moderate to high silica contents, K/Rb values (<283), sub-alkalinity and I-type peraluminous nature of the biotite granite, charnockite and biotite gneiss indicate that they are I-type granitoids. This suggests that the biotite granite, the charnockite and the igneous protoliths of the biotite gneiss are formed from crustal igneous-sourced melt(s) [21, 23, 24]. The igneous protoliths of the granite gneiss were probably formed from shallow crustal or sedimentary-sourced melt(s) as indicated by its S-type peraluminous character; occasional appearance of garnets and other

Al-silicate (especially muscovite) in its mineralogy as well as presence of quartzite inclusions in the rock at some locations.

Tectonic discrimination of Akungba-Akoko rocks revealed that they are all volcanic arc granitoids (Figure 6b) suggestive of rocks formed during a phase of magmatic activity related to collision and subduction [20, 25].

Conclusion

This study discussed the petrology, mineralogy, petrochemistry and petrogenesis of the Basement Complex rocks around Akungba-Akoko. The area is underlain mainly by migmatite, granite gneiss, biotite gneiss, biotite granite and charnockite. The gneisses in the area are orthogneisses formed by metamorphism of igneous protoliths of granitic composition. The biotite granite and charnockite are of igneous/magmatic origin. The biotite granite, charnockite and the igneous protoliths of the biotite gneiss were formed from crustal igneous-sourced melt(s), while the igneous protoliths of the granite gneiss were probably derived from shallow crustal or sedimentary-sourced melt(s). These basement rocks are volcanic arc granitoids formed during a phase of magmatic activity related to collision and subduction.

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