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Petrological Features and Geochemical Characterization of Igneous Rocks in Ado-Ekiti, Southwestern Nigeria

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Abstract: This research investigates and report petrological features and geochemical characteristics of igneous rocks in Ado-Ekiti, Southwestern Nigeria. Exhaustive geological fieldwork reveals Ado-Ekiti is underlain by migmatite-gneiss, quartzite, granite (porphyritic and fine-grained) and charnockite. Petrographic investigation revealed overwhelming presence of quartz, biotite and plagioclase in all the rocks while microcline and opaque minerals occur in subordinate amounts. Average SiO_2 content in porphyritic granite (74.56 %) is marginally higher than charnockite (73.51%) and fine-grained granite (70.41%). These values correlate well with previous works in the study area and agrees with similar rocks in other parts of the country. Analytical results using Phillips Panalytical PW1480 X-ray Fluorescence Spectrometer with Rhodium Tube as the X-ray source revealed the siliceous nature of the rocks. The binary plot (Na_2O+K_2O) *vs* SiO_2 established the rocks are granitic with all the samples plotting within granite field. AFM ternary diagram shows the rock have calc-alkaline affinity. Geochemical classification by (Na_2O + K_2O-CaO) vs SiO_2 diagram reveals the rocks are “Calc-alkalic and calcic”. The elevated K_2O (average of 4.41%) in the data signaled High-K calc-alkaline type on K_2O vs SiO_2 binary diagram. Alumina Saturation Index (ASI) showed the rocks are metaluminous while Al_2O_3 / (Na_2O + K_2O) *vs* Al_2O_3/ (Na_2O +K_2O +CaO) plot suggest the rocks have mantle origin.

Keywords: Ado-Ekiti, siliceous, calc-alkaline, metaluminous, mantle origin

Introduction

Ado-Ekiti in Southwestern Nigeria is popular for two reasons; first, it is the Administrative Capital of Ekiti State; and for this, it has drafted populations from several other towns making it the fastest growing and most populated town in Ekiti State. Secondly, it falls within areas of geological interest in terms of research. It is next to Ijero-Ekiti the home of many economic mineralization. Among others, prominent research works on the study area includes Oyinloye and Obasi, (2006) that reported on the geology and geochemistry of charnockite and granites in Ado-Ekiti. Ademeso (2010) reported the authors concluded that the granitic and charnockitic rocks were emplaced by fractional crystallisation of magma which was derived from the subduction of an ocean slab into the mantle in a back arc tectonic setting. Olarewaju, (1981) investigated the geochemistry of charnockite-granite unit in Ado-Ekiti-Akure area of Southwestern Nigeria. The author reported field observations which show remarkably close relationship while geochemical evidence provided a petrogenetic link between these rocks. Afolagboye, et al., (2015) evaluated crystalline rocks in Ado-Ekiti for suitability as construction aggregates. The authors reported dominance of quartz and feldspar in these rocks and the results of strength tests confirmed they fall within acceptable limits for general road construction aggregates. Jimoh and Boluwade, (2014) confirmed granite in the area are texturally and mineralogically suitable for quarrying. Tinuola and Owolabi (2007) reported on environmental pollution as a consequence of urbanization in Ekiti State. The authors testified to most health hazards being localized within Ado-Ekiti metropolis. Ige and Adetunji (2014) examined the relationship of some socio-economic factors and household sanitation in Ado-Ekiti. Oyedele, (2019) discussed the integrated methods for delineating groundwater resources in Ado-Ekiti. However, these earlier works did not focus on comprehensive petrologic implications of the geochemical characterization of these basement rocks. Hence this study presents petrologic implications of the geochemical features of igneous rocks in Ado-Ekiti.

Location of the Study area

Ado-Ekiti is the Administrative headquarter Ado Local Government. It falls within latitude 7º 30′ - 7º 49′ N of the equator and longitude 5º 07′ - 5º 27′ E. The sampling points spread across different parts of the metropolis which include Ori-Apata, Okeyinmi, Yinka quarry (Iyin Road) and Ajebandele (Fig. 1). The area is generally accessible with good roads network while most outcrop exposures are reachable and prominent.

The study area lies within the tropics and characterized by a climate with two seasons; rainy and dry seasons. The rains come between April and October while the dry season extends from November to March. The intensity of rainfall ranges between 50.8 mm during the dry season to 2413.3 mm during the rainy season; mean annual rainfall is about 1500 mm (Babatunde et al., 2007). Ado Ekiti is located on a flat terrain characterized by relatively low relief. However, there are several isolated dome-shaped bodies representing residual hills which are commonly granite. At the base of these rocks are boulders which littered the entire area (Ayoade et al. 1982). The major occupation of her inhabitants includes farming and trading. The major river draining Ado-Ekiti town is River Ireje which flows south-east. The river flows throughout the year but the volume reduces drastically during the dry season. Occasionally, it dries up leaving only few Pockets of wetland in case of extreme drought. River Ireje is a major tributary to River Ogbesse which is located on the far eastern side of the study area and flows directly into the Atlantic Ocean in the south.

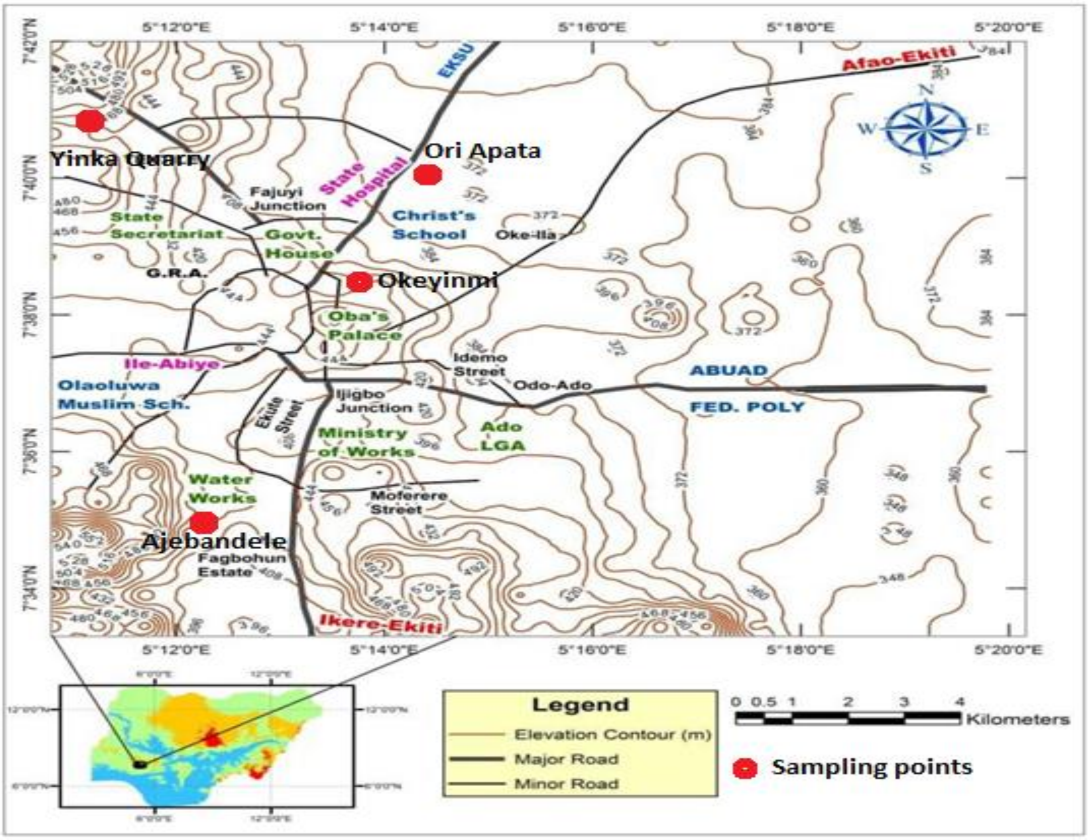

Figure 1: Topographic Map of Ado-Ekiti (modified after Oyedele, 2019).

Geological Setting

Regional geology

Nigeria falls within Pan-African reactivated terrain which lies on eastern side of West Africa craton and southern part of Tuareg Shield. The Pan-African terrain's origin was attributed to collision between passive margin of the West African craton and active continental edge of the Tuareg shield (Burke and Dewey, 1972; Dada, 2006). The study area lies within the basement complex of southwestern Nigeria which is one of the major areas where

Precambrian rocks are extensively exposed. The poly-orogenic terrain was last affected by the Pan-African tectono-thermal activity. Hence, rocks in the domain experienced widespread deformation during the Liberian, Eburnean, Kibaran and Pan-African orogenic cycles. The first three episodes were characterized by intense deformation resulting in complex isoclinal folds and extensive migmatisation. The Pan-African episode was the most penetrative, it was characterized by widespread granitization and homogenization of different basement gneisses which culminated in emplacement of syn-tectonic granites (Abaa, 1983). Late tectonic granites associated with contact metamorphism represented this late-stage deformation. The end of the orogenic activity was marked by faulting and fracturing (Gandu et al., 1986). The vast terrain contains migmatite-gneiss basement, schist belts and Pan-African granitoids.

Local geology

The geology of Ado-Ekiti area as part of the basement complex of Southwestern Nigeria is documented in the works of Hubbard, (1968); Cooray, (1972, 1975); and Olarewaju, (1987) to contain migmatite-gneiss, metasediments (mainly quartzite), granite, and charnockite. Field study (Olarewaju, 1987) shows the charnockite and granite are closely associated in time and space. Rahaman, (1981) believed the granite and charnockite are contemporaneous or that the charnockite is formed shortly after the emplacement of the granites. The metasediments occur as ridges and this forms part of the Nigeria schist belts (Bruguier et al. 1994). The charnockite was distinguished into coarse-grained, fine-grained and gneissic types (Tubosun et al. 1984; Olarewaju, 1987). Granite in the study area is mainly massive biotite-hornblende type with porphyritic texture and whale-back appearance. Strike of foliation in the country rock is northeast while the schistose rock dips west. The basement rocks in Ado-Ekiti area have undergone polycyclic metamorphism and are deformed like rocks in other parts of Nigerian basement complex (Oyinloye, 1995; Dada 1998). Outcrops are of average heights and sparsely vegetated. Ado-Ekiti is underlain by migmatite-gneiss, quartzite, granite, charnockite and metasediments mainly quartz–muscovite schists which occurs mainly as quartzite veins (Fig. 2).

Migmatite

Migmatite-gneiss is basal to all other rock units in the study area. It shows heterogeneous assemblage of migmatite and gneisses with complex deformation styles attributed to polycyclic orogenic events. This unit occurs as denuded low-lying masses. The rock unit is composed of mafic portions made up of biotite, hornblende and opaque minerals and felsic portion of quartzo-feldspartic aggregates. Compositional variation in this lithology is dictated by closely spaced alternating bands of leucocratic and melanocratic minerals. Some of the lithology appeared banded thus resembling gneisses with alternation of light and dark-colored aggregates. Migmatite occurs extensively on the north and eastern part. However, other outcrops occur in central part and extends to southwestern part of the study area. Migmatite outcrops in the study area are low-lying and have suffered intensive chemical weathering such that there is scarcely of fresh samples for study. By coverage, the rock unit covers about half of the entire landmass.

Migmatite-gneiss

This unit is restricted to southern part of the study area. This lithology in some parts look like migmatite while in other parts it looks gneissic. Morphologically the outcrops take resemblance of migmatite in that it is generally low-lying.

Quartzite

Quartzite veins in Ado Ekiti occurs as small ridges rising 100m above the surrounding terrain. Quartzite veins are small quartz vein intrusions within the host rocks prior to metamorphic transformation. Quartzite veins are smaller masses having a sense of alignment and orientation. The massive quartzite on the other hand occurs as large outcrops that are immensely jointed, fractured but non-foliated. The rock consequent on its resistant to both physical and chemical weathering is very prominent and occurs mainly in the central and southwestern part of the study area. Massive quartzite forms when quartz-rich sandstone (arkose, greywacke or cherts) is subjected to increased temperature and pressures within the earth. Such conditions transform quartz grains into a dense and hard rock mass. The name quartzite symbolizes rocks dominated

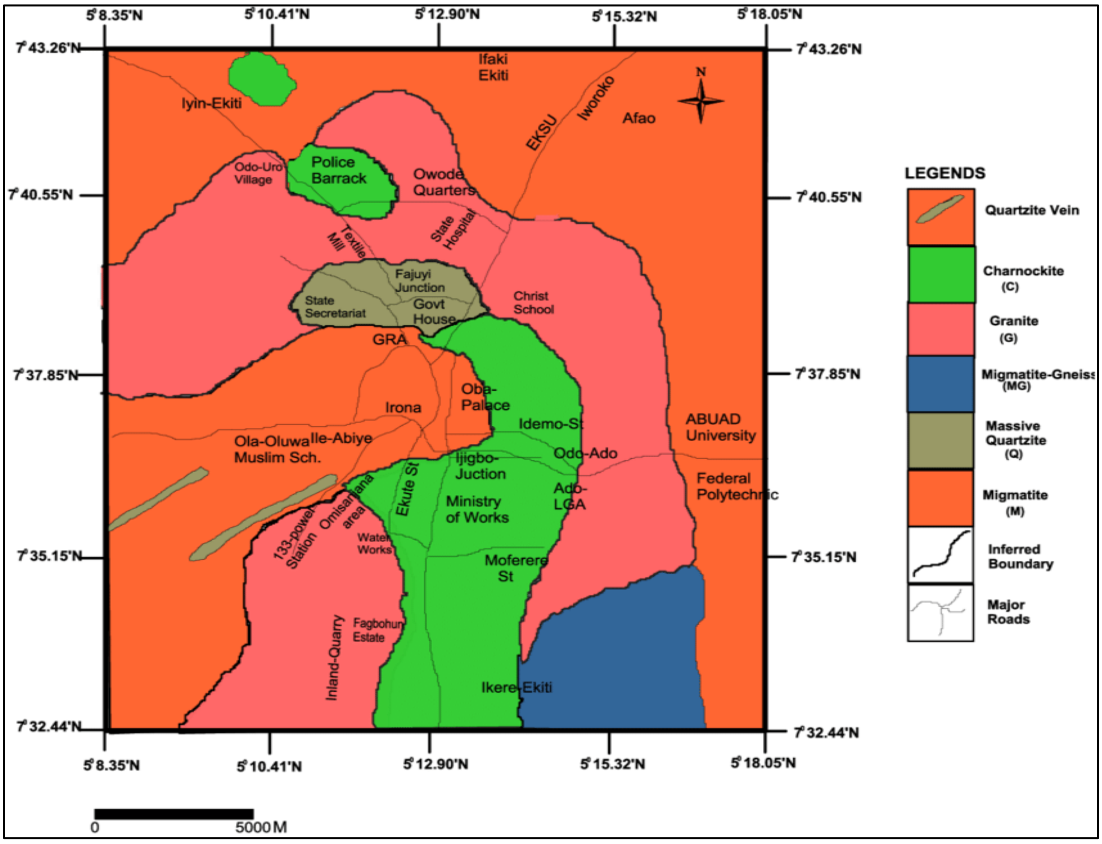

Figure 2: Geological map of Ado-Ekiti (modified after Akintounrinwa et al. 2020).

By quartz grains that is highly indurated. Despite the prominence of quartzite in the study area, it close association with lateritic soils has impacted a reddish hue on the rock. Consequent on the understanding of its monotonous chemistry, quartzite in the study is not presented for geochemical analysis.

Granite

Both porphyritic and fine-grained granite are mapped in the study area. Porphyritic granite occurs at Oriapata along Ekiti State University Road, and Yinka quarry located along the Old-Iyin Road. The rock is characterized by pinkish feldspar phenocrysts. Generally, granite is widespread type of felsic igneous rock with granular and crystalline texture. It is composed of quartz, feldspar, mica (biotite, muscovite or both) and hornblende. Outcrops of porphyritic granite in Ado-Ekiti are nearly always massive (lacking any internal structure). The rock is hard and tough; therefore, it has gained widespread uses because of its natural beauty which could be enhanced by polishing and partly because of its abundance. The fine-grained type is of restricted occurrence and found around Okeyinmi area. The post formational structures observed on these rocks include joints, dykes, fractures, veinlets, and quartz veins.

Charnockite

Charnockite forms extensive outcrop in the study area, the rock unit exhibits slight variation in texture. The charnockite rocks in the study area occur as prominent low-lying outcrops with smooth rounded boulders surrounding the main masses. They are generally dark-green in color especially those exhibiting coarse texture. The charnockite is generally less resistance to weathering and the color of the fine-grained variety is dark-green to grayish. According to Boluwade et al. (2018), the mineral composition of the Ado-Ekiti charnockite are quartz, alkali feldspar, and the ferromagnesian minerals like hornblende, olivine, pyroxene and biotite while other minerals of lesser abundance include zircon and apatite. Charnockite in the study area are located near the WAEC office in Ajebandele. Larger masses are also common along Ado-Ikere Road.

Methods

The research is carried out in two stages. These include fieldwork and laboratory works.

Fieldwork

This fieldwork involves mapping and taking traverses across the entire terrain following already existing major roads, minor roads and bush paths. During fieldwork, fresh samples of the rock types from different locations are collected. Sampling was achieved by selecting fresh samples following the best geological practices. It involves taking samples from widespread localities to ensure that all textural varieties of the rock unit are considered in the sampling population. Random sampling method was adopted in the study. Samples were collected from Ori-Apata, Okeyinmi, Yinka quarry and Ajebandele areas. During fieldwork, field tools are used. The various materials include: a *Geological Hammer* for chipping rock samples from large outcrops. For ease of identification, samples are labelled with masking tape. A *Global Positioning System (G.P.S)* with signals from satellites in the space, it processes data which was plotted to track positions on earth at any given time. The GPS take coordinates and elevations above the mean sea level. A *Field note* is used to record all information gathered in the field and the description of different rocks in-situ, the field notebook is always accompanied by writing materials (pen, pencil and colored pencil) for sample description and inscription. *Sample Bags* are used for conveying samples to the laboratory for further analysis, the bags prevent the samples from mix-ups. A *digital Camera (COOLPIX LX 80)* is used to take photographs of the samples and structures in their in-situ positions. A *Compass Clinometer* is used to measure the strike of foliation as well as the dip directions in the host country rock. It also helps to measure the degree of a plunging fold. A *Chisel* is often used together with the hammer when carefully chipping a delicate sample and to prevent much fragmentation.

Laboratory works

Among several laboratory devices used in this research are: *Jaw Crusher*: For the preparation of laboratory sample for analysis. It has an adjustable discharge size, giving the freedom to select the grain size of an output. *Methylated Spirit:* to clean the equipment after every use to prevent contamination of samples during crushing and milling. *Milling machine:* this is a multi-task machine which is capable of pulverizing and turning the samples as well. A *Petrological Microscope:* this optical device enlarges the image of rock slides placed on the stage. The equipment can also carry out other measurements such as the cleavage directions and extinction angle of a mineral. Petrological microscope uses polarized light to identify rocks, minerals and micro structures in thin sections.

Procedure for petrographic Analysis

Representative samples were prepared for thin section to determine the minerals in the rocks using standard petrographic procedures. A suitable size slab for mounting a slide was cut from each rock sample and lapped on a lapping machine. Silicon carbide was put on the lapping glass which was placed on the lapping table with some water added until the surface becomes smooth. Thereafter, the samples were moved to the thermo plate and washed with water and the thermo plate was switched on to 120°C for an hour to remove excess water from the specimen through a process known as baking. Thereafter, the specimen was removed from the hot plate and allowed to cool at room temperature. The specimen was later mounted on a glass slide by araldite and taken to the cutting machine for size reduction. The reduced specimen was taken to the lapping machine via a lapping jig for final reduction to the required thickness of 0.05mm which is the standard thin section thickness. After achieving this thickness, the specimen is removed from the lapping jig and washed properly to remove excess slurry around it. After washing, it was allowed to dry, and then covered with glass slips using Canada balsam which was washed by methylated spirit and detergent. The specimen was then rinsed properly with water. It is allowed to air dry and then labelled for microscopic analysis. Petrographic analysis of the rock samples was carried out by examining thin section of the rock samples under petrographic microscope. Average mineralogical composition was calculated to get the modal composition.

Analytical Procedure

XRF analytical method was adopted for geochemical evaluation of the samples in the research. The experimental procedure was similar to those in Akinyemi et al. (2011). The pulverized rock samples were oven-dried at 100°C for 12 hours to determine the adsorbed water prior to analysis. The powdery samples were then mixed with a binder (ratio of 1: 9 in grams of C-wax and EMU powder) at a ratio of 2: 9 (2 gm binder and 9 gm sample). The mixture was then pelletized at a pressure of 15 Kbar for 1 minute. Loss on ignition experiment was performed prior to major element analysis and for accuracy of the analytical results. A Phillips Panalytical PW1480 X-ray Fluorescence Spectrometer with Rhodium Tube as the X-ray source was used. The technique reports concentration as percentage oxides for major elements and ppm for trace elements. The XRF analyses was undertaken at the School of Environmental Sciences, University of Venda, South Africa.

Results

Petrography

The modal composition of the basement rocks in the study area is presented (Fig. 3 [a-f]). Each slide represents investigation under cross polarized light (xpl) and the other, plane polarized light (ppl). Porphyritic granite contains biotite (48.2%), quartz (43.6%), microcline (5.7%) and

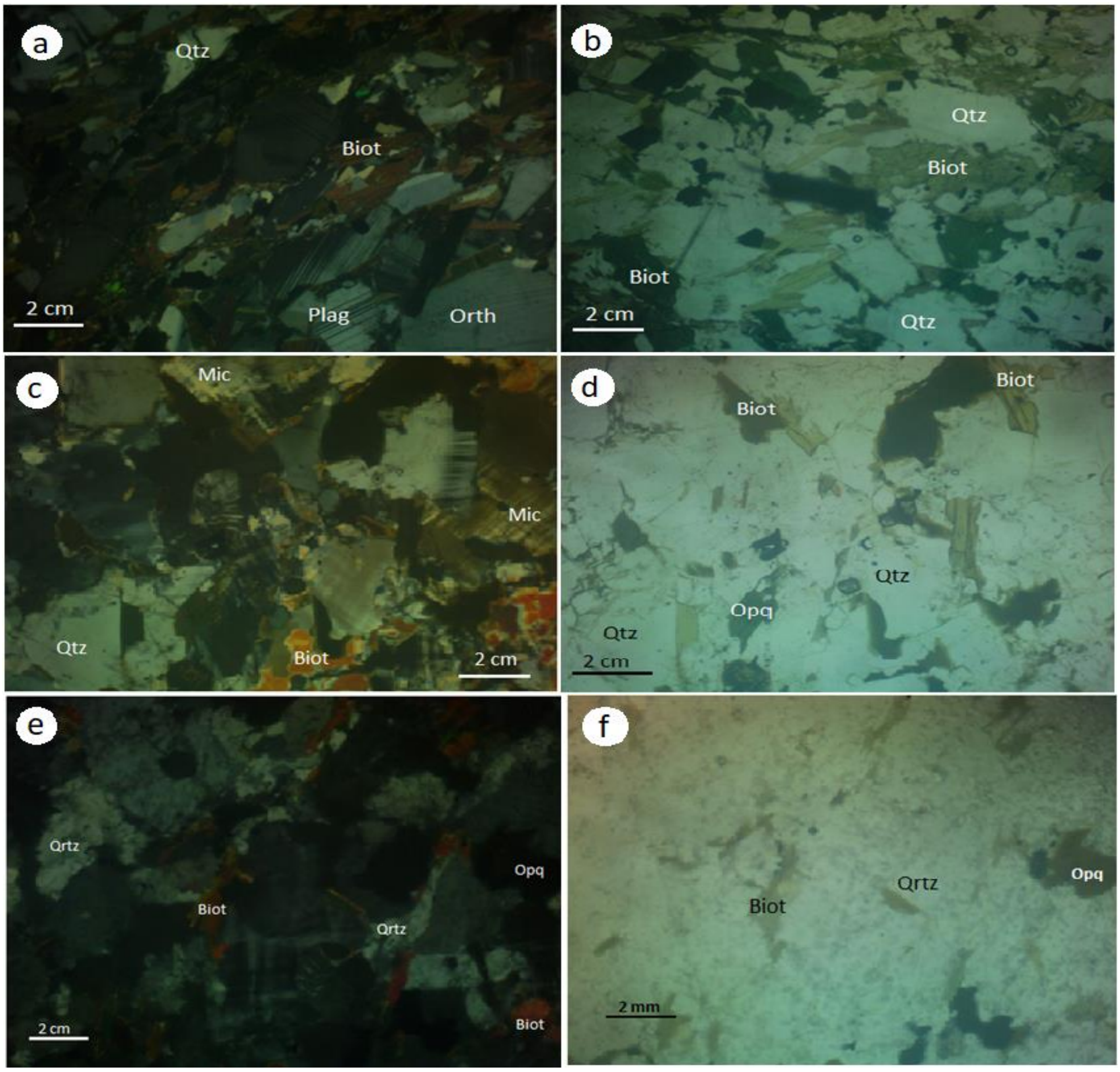

Figure 3: Photomicrograph of **(a)** porphyritic granite from Ori-Apata, Ado-Ekiti in transmitted light [cross polarized light]; (b) plane polarized light showing the constituent minerals-; (c) fine-grained granite from Okeyinmi area, Ado-Ekiti [cross polarized light], (d) the fine-grained granite under plane polarized light showing the constituent minerals; (e) charnockite in Ajebandele area of Ado-Ekiti in transmitted light [cross polarized light], (f) the charnockite as observed under the plane polarized light. {Biot (biotite), Qrtz (quartz) and Opq (opaque), Plag (plagioclase), Orth (Orthoclase), Mic (microcline)}.

Table 1: Mineralogical Composition of the Rock Samples (vol. %).

		Porphyritic Granite (A)					Porphyritic Granite (B)			
Minerals	S1	S2	S3	Total	%	S1	S2	S3	Total	%
Biotite	34	10	8	42	48.2	40	42	31	113	45.4
Microcline	1		4	5	5.7	-	-	-	-	-
Quartz	16	12	10	38	43.6	7	9	8	24	9.6
Plagioclase		1	1	2	2.2	10	7	4	21	8.4
Opaque						24	32	35	91	36.5
				87	99.7				249	99.9
		Porphyritic Granite (C)					Fine-grained Granite (A)			
Minerals	S1	S2	S3	Total	%	S1	S2	S3	Total	%
Biotite	23	14	25	62	57.4	37	15	20	72	62.1
Plagioclase	3	4	5	12	11.1	2	-	-	2	1.7
Microcline	-	-	-	-	-	6	5	3	14	12.1
Quartz	10	14	10	34	31.5	5	4	9	18	15.5
				108	100				116	91.4
		Fine-grained Granite (B)					Fine-grained Granite (C)			
Minerals	S1	S2	S3	Total	%	S1	S2	S3	Total	%
Quartz	3	2	3	8	8.2	4	6	5	15	16.3
Microcline	5	1	4	10	10.2	5	6	1	12	13.0
Biotite	15	21	23	59	60.2	17	16	28	61	66.3
Plagioclase	2	3	1	6	6.1	1	-	1	2	2.2
Opaque	-	-	-	15	15.3	-	1	1	2	2.2
				98	100				92	100
		Charnockite (A)					Charnockite (B)			
Minerals	S1	S2	S3	Total	%	S1	S2	S3	Total	%
Biotite	10	8	5	23	44.2	18	10	13	41	32.5
Microcline	5		3	8	15.4	6	5	5	16	12.7
Quartz	4	4	3	11	21.2	12	7	10	29	23.0
Plagioclase		1	1	2	3.8	10	5	5	20	15.9
Opaque		3	2	5	9.6	-	-	-	-	-
Muscovite		1	2	3	5.8	4	6	10	20	15.9
				52	100				126	100

Plagioclase 2.2%. Quartz grains appear as large subhedral crystals with white color. Biotite occurs as brown acicular crystals with high aspect ratios. Plagioclase are large subhedral to anhedral crystals, smaller plagioclase masses occur in clusters while orthoclase occurs as large crystals with grey color (Fig. 3a and 3b). Fine-grained granite contains biotite (74.4%), quartz (18.3%), microcline (14.6%) and plagioclase 2.4% (Figure 3c and 3d). Quartz grains are small clear crystals with subhedral shapes, biotite laths appear as stretched mineral with diagnostic light brown to dark-brown colour, the minerals are randomly oriented. Microcline has variable colours which ranges from grey in small grains and dark in large crystals. The large crystals exhibit characteristic grid (cross-hatched) twinning and sometimes appears as conspicuously largemineral constituent on the stage. The modal composition of charnockite (Figs. 3e and 3f) reveals the rock contains biotite (63.3%), quartz (15.2%), microcline (6.3%), and plagioclase (1.3%).

Charnockite shows a fine texture with biotite varying between brown and dark-brown, the mineral spreads in all direction on the stage. Quartz appear as white subhedral grains with medium sizes. Some minerals go into extinction at 30° when rotating the stage. Few opaque minerals appear black on the stage because it does not allow light to pass through it.

Geochemistry

Analytical result (Table 2) reveals silica contents of the rocks range between 70.41- 74.56 %, alumina contents between 10.04- 11.57 % and MnO 0.03- 0.07%. However, average SiO_2 content in porphyritic granite (74.56 %) is higher than charnockite (73.51%) and fine-grained granite (70.41%). These values correlate well with granites in other parts of the country. The result equally agrees with previous works in the study area. For instance, Obasi and Talabi, (2019) reported silica content of 65.64-74.23% for granite in Ado-Ekiti. Oyinloye and Obasi, (2006) reported that the porphyritic granite contains 73.52-75.43% while the medium-grained granite contains 73.52-75.43% silica. However, these values are higher than the Rahama amphibole-biotite granite (65.59-67.87%), Monzonite (62.92-67.79%) and Toro amphibole-biotite granite (65.74-69.18%) (Ferré et al. 1998) from the basement complex of north central Nigeria. Alumina (Al_2O_3) content in the granite (10.04 - 11.50%) is comparable to charnockite (11.46-11.63%). This result is lower than the values (12.02-16.43%) presented by Obasi and Talabi, (2019) and Obiefuna, et al. (2018) in Michika granite of Northeastern Nigeria (11.554 -18.961 %). Fe_2O_3 contents in Ado-Ekiti granite (1.54% to 4.87%) and charnockite (3.13 -

Table 2: Analytical results of the igneous rocks in Ado-Ekiti

Oxides	RK1	RK2	RK3	RK4	RK5	RK6	RK7	RK8	RK9	RK10	RK11	RK12	Avg.
	Porphyritic Granite				Fine-grained granite				Charnockite				
SiO_2	74.21	72.88	73.57	70.41	70.41	71.43	72.52	71.91	74.56	71.43	72.08	73.5	72.41
Al_2O_3	10.72	10.44	10.04	11.51	10.89	11.17	11.19	10.52	10.73	11.47	11.57	11.6	10.99
Fe_2O_3	4.08	4.87	4.76	4.33	4.33	4.21	4.17	3.91	1.54	3.71	4.47	3.13	3.96
CaO	2.14	1.98	2.02	2.27	2.53	2.44	2.44	2.01	1.21	1.89	2.5	1.81	2.10
Na_2O	3.25	3.18	3.09	3.4	3.21	3.29	3.16	3.32	3.18	3.26	3.15	3.14	3.22
MgO	0.56	0.9	0.82	0.71	0.99	0.8	0.71	0.44	-	0.43	0.76	0.62	0.70
K_2O	4.2	4.36	3.92	4.7	4.37	4.36	4.36	4.12	4.64	4.57	4.19	5.08	4.41
P_2O_5	0.09	0.15	0.07	-	0.32	0.14	0.12	0.07	-	0.11	0.13	0.05	0.12
MnO	0.06	0.06	0.05	0.03	0.04	0.03	0.03	0.04	0.01	0.03	0.07	0.05	0.04
TiO_2	0.52	0.59	0.56	0.52	0.54	0.49	0.49	0.41	0.15	0.38	0.36	0.16	0.43
Total	99.83	99.41	98.91	97.88	97.63	98.36	99.19	96.75	96.02	97.28	99.28	99.2	98.31
S/A	6.925	6.983	7.327	6.118	6.466	6.396	6.483	6.838	6.946	6.228	6.229	6.32	6.59
S/N	22.83	22.92	23.81	20.71	21.93	21.71	22.95	21.66	23.45	21.91	22.88	23.4	22.49
S/K	17.67	16.72	18.77	14.98	16.11	16.38	16.63	17.45	16.07	15.63	17.2	14.5	16.43
S+K	78.41	77.24	77.49	75.11	74.78	75.79	76.88	76.03	79.2	76	76.27	78.6	76.82

S/A = (SiO_2/Al_2O_3); S/N = (SiO_2/Na_2O); S/K = (SiO_2/K_2O); S + K = ($SiO_2 + K_2O$)

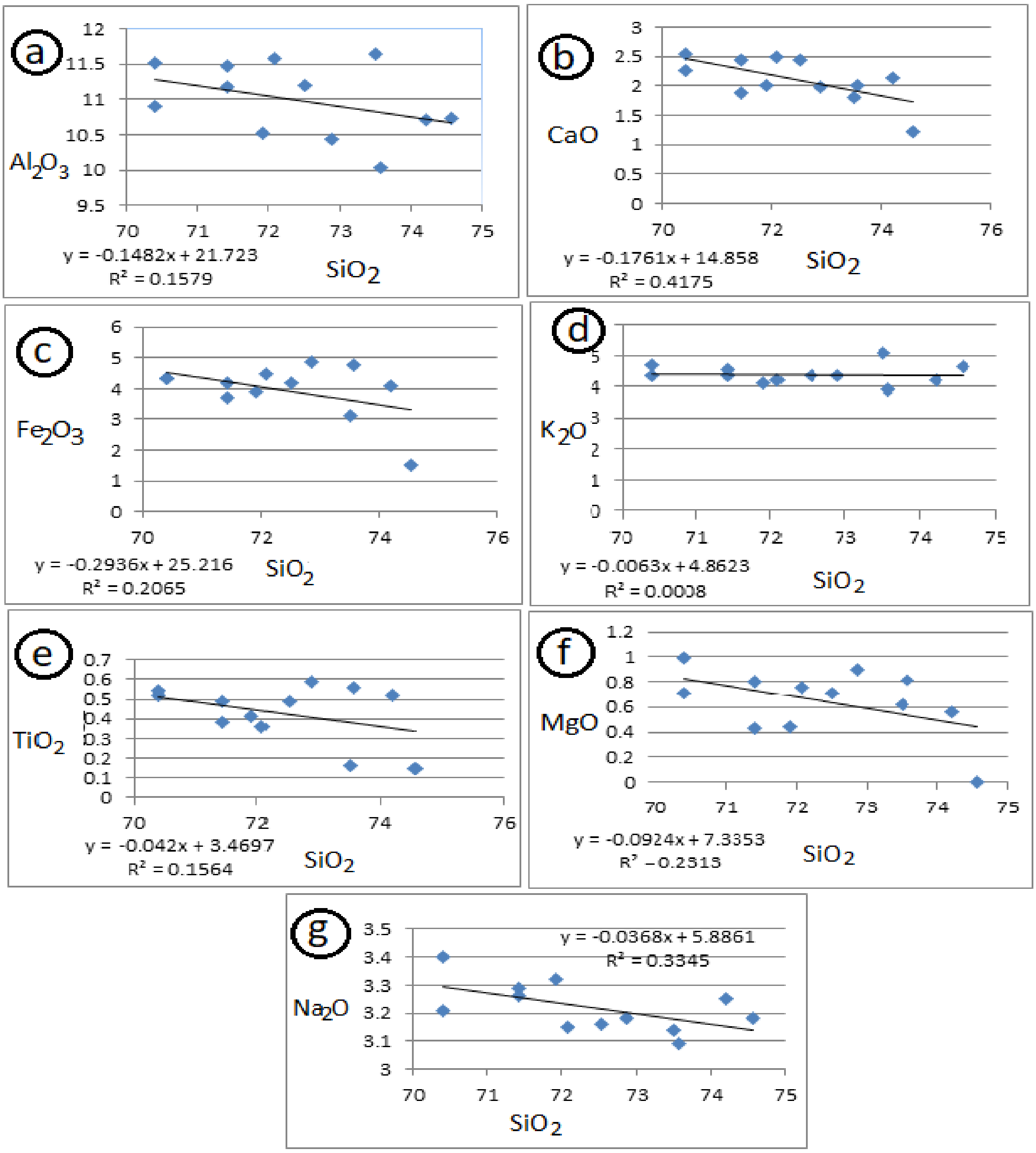

Figure 4: Harker diagrams of major oxides against SiO_2 for igneous rocks in Ado-Ekiti.

4.48%), falls within shorter range (2.71-6.76 %) reported by Talabi and Obasi, (2019). Potash (K_2O) content in the granite and charnockite (3.92-5.08%) reflects abundance of feldspar in the rocks, this may equally indicate albitization. The high iron ratio may reflect presence of secondary opaque phase (magnetite). TiO_2 values are generally < 1 %, this falls within the range accepted in calc-alkaline rocks (Table 2).

Harker variation plots (Fig. 4a-g) of major oxides (Al_2O_3, CaO, Fe_2O_3, TiO_2, MgO, Na_2O) against SiO_2 reveals negative trends except K_2O. The negative trends are expected as it indicates fractionation during magmatic crystallization in which signifies these oxides should decrease with increasing SiO_2. This reveals that as early minerals crystallized from the magma, these elements are partitioned into the rock forming minerals that takes them up during crystallization. The variation between K_2O vs SiO_2 indicates K_2O maintained a constant value irrespective of the values of SiO_2. This relationship may reflect albitization, a process where primary feldspar is replaced by albite.

The binary plot (Na_2O+K_2O) *vs* SiO_2 (Cox et al. 1979) (Fig. 5a), established the rocks are granite with all the samples plotting within the granite field. In AFM ternary diagram (Fig. 5b), all rock samples plot within calc-alkaline series field rather than tholeiite series. ($Na_2O + K_2O$-CaO) vs SiO_2 diagram (Fig. 5c) reveals the basement rocks plot in the "Calc- Alkalic and Calcic" fields. A thorough observation of the data shows the rocks have high K_2O (average of 4.41%) which discriminate the rocks as high-K_2O (High-K calc-alkaline series) on the plot of K_2O vs SiO_2 (Fig. 5d). Alumina Saturation Index (ASI) defined by molecular ratio for classifying rocks into peraluminous, metaluminous, peralkaline, S-Type and I-Type granite; all samples using ASI index plotted in the metaluminous I-type field. The plot of Al_2O_3 / ($Na_2O + K_2O$) *vs* Al_2O_3/ ($Na_2O + K_2O + CaO$) indicate the samples plotted in metaluminous field suggesting the rocks probably originated from magma of mantle origin. Furthermore, the molecular ratio of alumina to alkalis (Shand, 1943), that is, Al_2O_3/ ($Na_2O + K_2O$) *vs* Al_2O_3/($CaO+Na_2O+K_2O$) [A/NK *vs* ACNK] classified igneous rocks in Ado-Ekiti as granite with metaluminous affinity (Fig. 6a). According to Frost et al., (2001), alkalic rocks are less likely to be peraluminous, while calcic and calc-alkalic rocks are not likely to be peralkaline. The granite rocks are distinctive for being highly potassic.

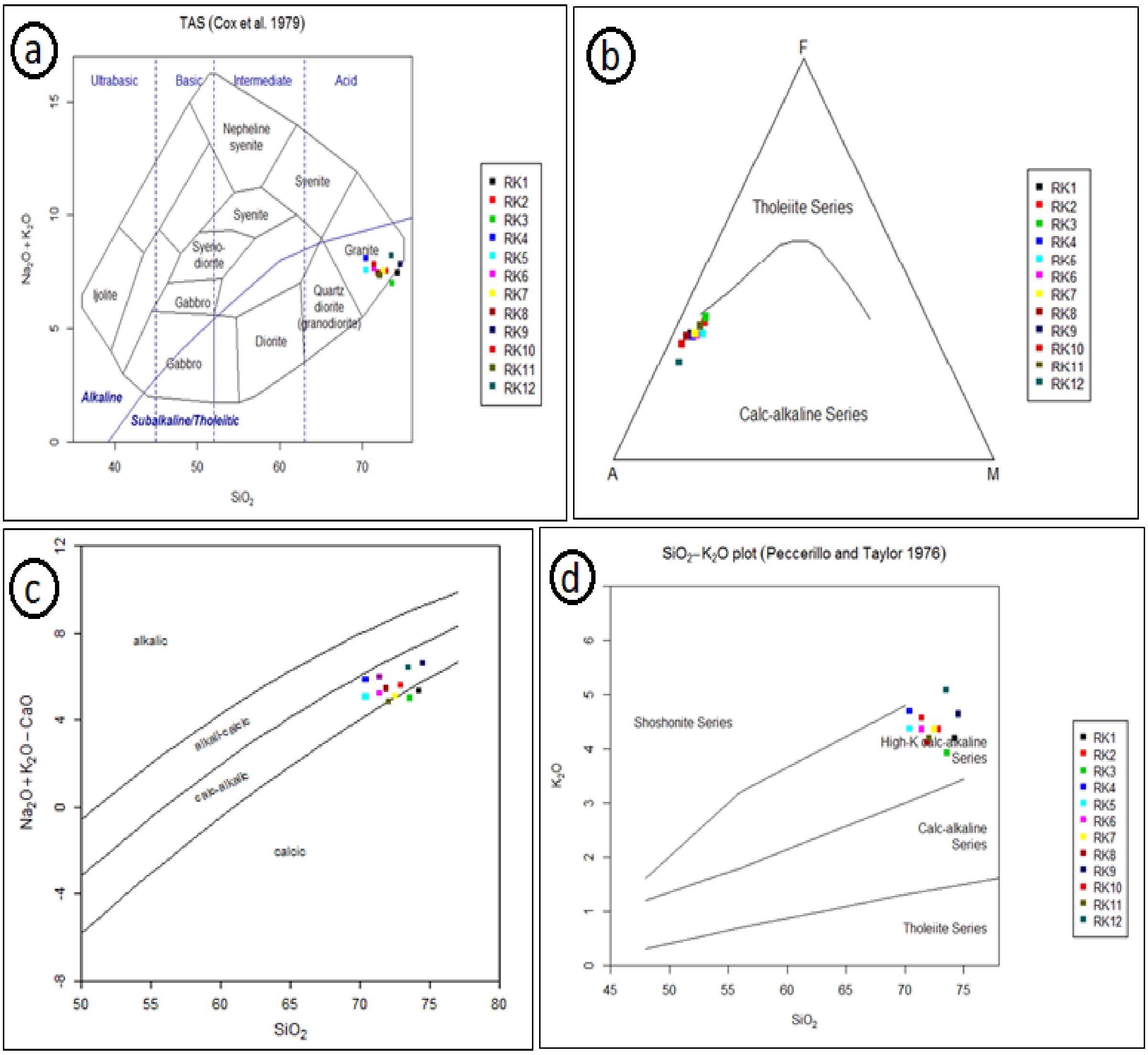

Figure 5: (a) Binary plot (Na_2O+K_2O) *vs* SiO_2 (Cox et al. 1979), (b) AFM ternary diagram, (c) (Na_2O+K_2O-CaO) *vs* SiO_2 diagram, and (d) K_2O *vs* SiO_2 diagram (after Peccerillo and Taylor, 1976) of the igneous rocks in Ado-Ekiti.

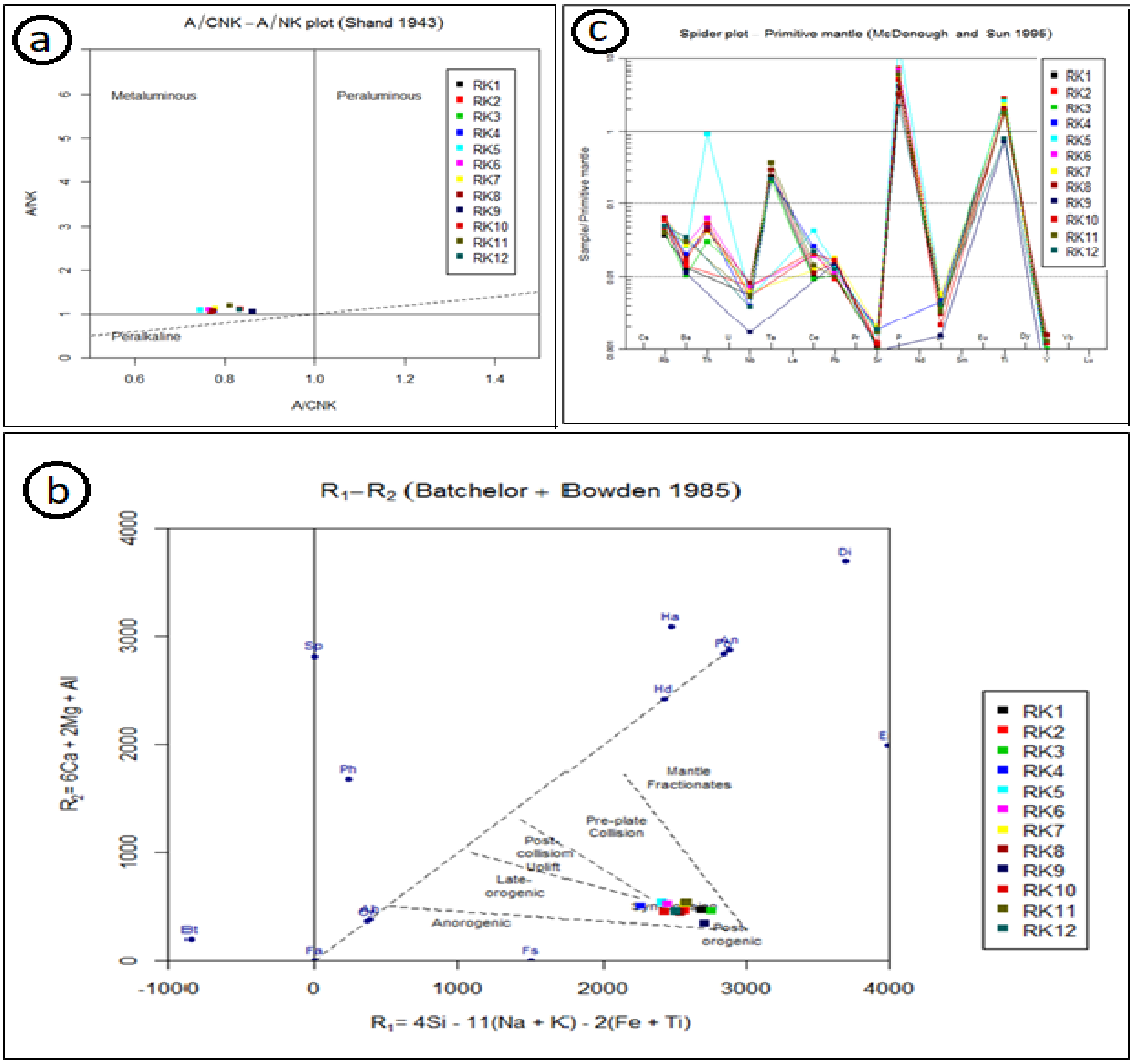

Figure 6: Binary diagrams of (a) ANK *vs* ACNK of the rocks, (b) R_1-R_2 diagram, and (c) primitive mantle-normalized spider diagram of igneous rocks in Ado-Ekiti.

Classification of the igneous rocks based on R_1-R_2 (Batchelor and Bowden, 1985) where $R_1 = 4Si - 11(Na + K) - 2(Fe + Ti)$, and $R_2 = 6Ca + 2Mg + Al$ (Fig. 6b). This binary plot reveals the igneous rocks are syn-orogenic; meaning the origin of these rocks is contemporaneous with orogenic activity of the Pan-African. Trace elements concentrations in the rock samples and their primitive mantle patterns normalized to average crust showed trace elements concentrations of the Precambrian rocks against primitive mantle-normalized spider diagram (Fig. 6c). The data exhibit notable spikes of enrichments in Eu, P and Ta (Sun and McDonough, 1985) with all samples showing consistent patterns of negative anomalies for Nb, Sr, Zr, Ce, Y, Pb, La, Th and Ti.

SUMMARY

In this research, the following conclusions are made.

(1) Field mapping reveals the study area is underlain by migmatite-gneiss, quartzite, granite and charnockite. Migmatite in the study area is mainly low-lying, quartzite is ferruginous while the porphyritic granite occurs as prominent massive bodies, the fine-grained granite is of average elevations and the charnockite masses occur in close proximity to the granite.

(2) Petrographic examination revealed quartz, biotite and plagioclase are common to all the basement rocks while microcline, muscovite and opaque minerals occur in subordinate amounts.

(3) Analytical result indicates all the igneous rocks are siliceous; However, the units have marginally higher silica values than the Rahama amphibole-biotite granite, Monzonite and Toro amphibole-biotite granite from north central Nigeria.

(4) Geochemical characterization defined by (Na_2O+K_2O) *vs* SiO_2 established the rocks are granitoids. AFM ternary diagram portray the rocks as calc-alkaline and not tholeiitic series. (Na_2O+K_2O-CaO) *vs* SiO_2 diagram reflects its Calc-alkalic and Calcic nature, the rocks have high K_2O, thus they are high-K calc-alkaline series on K_2O vs SiO_2 diagram. Alumina Saturation Index (ASI) defined the samples in metaluminous I-type field. The plot of Al_2O_3 / (Na_2O + K_2O) *vs* Al_2O_3/ (Na_2O +K_2O +CaO) indicate the silicate melt that produced the rocks samples is of mantle origin.

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Conflict of Interest

The authors declare that there is no conflict of interest in this paper.

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