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Petrography and Geochemistry of Orin-Ekiti Basement Rocks, Southwestern Nigeria: Implications on Bauxitization

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Abstract: The petrography and geochemistry of Orin-Ekiti Basement rocks were evaluated to determine their mineralogical and chemical composition, assessed their petrogenesis and susceptibility to the formation of bauxitic clay. Ten representative rock samples were selected for thin section petrography and bulk rock geochemical analysis using Petrographic microscope and XRF, Rh Tube, 3k Watt respectively. Field observations revealed charnockites as the dominant rock in the study area with other lithotypes including granite, granite gneiss and banded gneiss. Optical examinations indicated the dominance of quartz in all the rocks suggesting the rocks are product of acidic magma. The order of oxides concentration (wt%) is $SiO_2 > Al_2O_3 > Fe_2O_3 > CaO > K_2O > MgO > Na_2O > TiO_2 > P_2O_5$. Based on silica content only, the rocks in this study are classified as felsic (granite, granite gneiss and banded gneiss) with $SiO_2 > 65\%$ and ultramafic (charnockites) with $SiO_2 < 45\%$. Charnockites with low SiO_2, high Al_2O_3 and TiO_2 compared to other rocks in the study area is considered more favourable to form bauxite. The rocks in the study area are classified into calcic-alkali and calcic groups with igneous protolith.

Keywords: Basement Rocks, Bauxitization, Thin Section, Geochemical Analyses, Protolith

Introduction

Ekiti State is naturally endowed with numerous natural resources and potentially rich in rocks and mineral deposits including granite, kaolin, columbite, charnockite, iron-ore, barite, aquamarine, gemstone and bauxite to mention a few (Kashim, 2011; Malomo, 2011). Weathering that represents the chemical and physical processes that change the characteristic of rocks on the earth's surface is responsible for the formation of many ore deposits. Bauxite and laterite may result from the weathering of any one of many types of rocks or their weathered derivatives. However, rocks of originally high or moderately high alumina content and with a relatively large percentage of soluble constituents lend themselves more readily to lateritization and bauxite formation (Taylor and Eggleton, 2012). Important bauxite deposits are known to occur on limestone (those in central Europe and the Mediterranean region), on diorite, syenite, granite and metamorphosed volcanics and sediments, (as those in the Guianas, Malaya and Netherlands Indies), on nepheline syenite and phonolite (as in Arkansas, USA, Pocos de Caldas, Brazil and the Los Islands, French Guinea), on arkose, slate and phyllite (as on the French Guinea mainland and in Gold Coast), on basalt (as in central India) and on sedimentary clays, as in southern Georgia and Alabama, USA. Besides rock types, the composition of ground water, topographic relief and climatic conditions such as temperature and rainfall, influence lateritization and bauxite formation to an important extent (Harder, 1949; Gu *et al*., 2013).

Bauxite is the main source of aluminum in the world. Bauxite ore deposits originate either by in-situ weathering of aluminium silicate rocks or by allochthonous sedimentation after erosion of bauxite soil blankets. Lateritic soil results from weathering of rocks especially in the tropics and subtropical climate of the world. When such soil is severely leached of silica and other soluble materials, bauxite could form. Alumina is immobile in weathering environments, TiO_2, common in bauxites, is also immobile, while SiO_2, FeO and the alkalis are all readily mobile and therefore removed leaving Al_2O_3 and TiO_2 to concentrate with lesser amounts of SiO_2 and Fe_2O_3 and high Al/Fe ratio (Wilson, 2004). Many aluminum silicate rocks contain an average of 15% Al_2O_3 that must be regraded by weathering to at least 35% Al_2O_3 to be economically exploitable. Alumina enrichment ensues by leaching of substances that are not easily dissolved especially silica, the alkalis and iron. Many different types of Bauxite are known all over the world. Of all the known bauxite deposits, about 88% are lateritic type, 11.5% are karst type and the remaining 0.5% is Tikhvin type (Bardossy, 1982). Lateritic-type deposits form upon aluminosilicate rocks via in-situ lateritization. In such cases, the most important factors in determining the extent and grade of Bauxite formation are the parent rock composition, climate, topography, drainage, groundwater chemistry and movement, location of the water table, microbial activity and the duration of weathering processes (Grubb, 1963; Bardossy and Aleva, 1990; Price *et al*., 1997). Karst-type deposits occur within depressions upon karstified or eroded surfaces that formed upon carbonate rocks. Such deposits originate from a variety of different materials, depending upon the source area (Bardossy, 1982). Finally, Tikhvin-type deposits are transported or allochthonous deposits that overlie alumosilicate rocks and that originate from pre-existing residual laterite profiles (Bardossy, 1982; Bardossy and Aleva, 1990). Among several mineral deposits in Nigeria are bauxite deposits found in four states (Plateau, Ondo, Ekiti and Adamawa) of the federation (Keselj *et al*., 2012). This research focused on petrography and geochemistry of Orin Basement rocks with a view to discriminate the petrogenesis of the rocks and conclude on their suspectibility to bauxitation.

Location and Geology

Orin-Ekiti (study area) is about 38.8 km from Ado-Ekiti, lies on latitude $7^0 49'48.00''$N and longitude $5^0 14'24.00''$E with terrain that is gently undulating. The topographic elevation of the area ranges between 535-588 m above sea level (Fig. 1). Its climate is characterized by dry and wet season in a year. The dry season occurs between November and March, while the driest is in the month of December and January. The wet season is between April and October, while the highest rainfall is recorded in July and September. The average annual rainfall is 1333.2 mm. The annual temperature is 33°C while the minimum is 18°C. The principal rock outcrops are granite gneiss, banded gneiss, granite and charnockite especially the coarse grained type (Fig. 1). Generally, the terrain is rugged with boulders of charnockite outcropping in few locations (Talabi *et al*., 2013). Most of the area is fairly accessible as it is connected with network of tarred and unpaved roads. However, some settlements are only connected by footpaths. The area is sparsely populated and farming activities in the area have made accessibility to some outcrops possible.

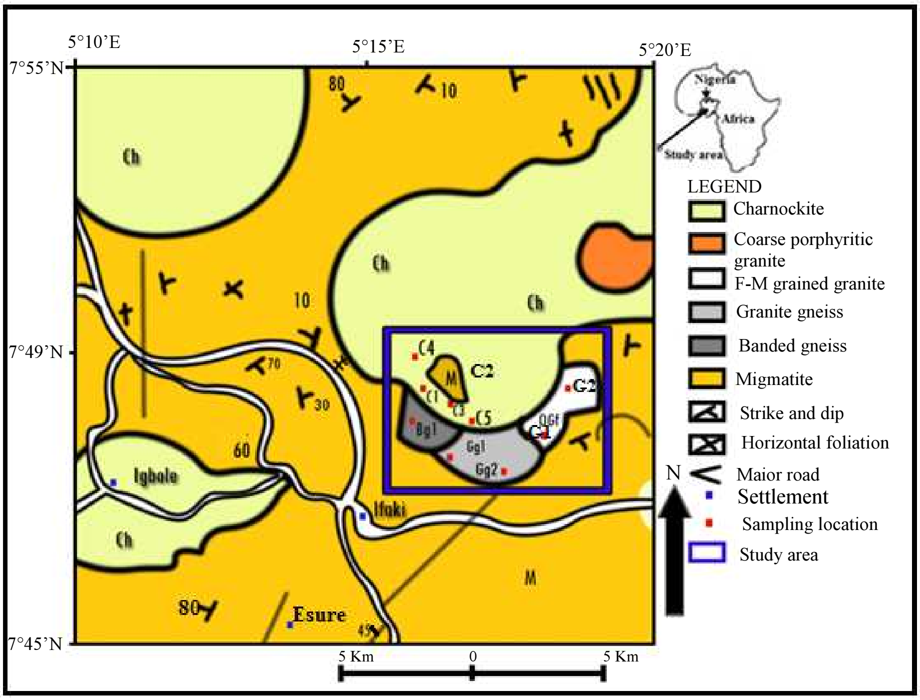

Fig. 1: Location and geologic map of the study area (modified after Talabi *et al*., 2013)

Materials and Methods

Representative fresh rocks samples were taken within the indicated study area (Fig. 1). Fresh rock was broken into smaller fragments employing a sledge hammer. The rock fragments were placed into small plastic bags and labeled with a sample number and the appropriate location. The samples collected were also marked on the field map. This procedure was repeated at each location. These points were later transferred to Geologic Map (Fig. 1). Ten rock samples (5charnockites, 2granite, 2granite gneiss and 1banded gneiss) were selected and prepared into thin section at the Petrology Laboratory, Applied Geology Department, Federal University of Technology, Akure, Nigeria for optical examination. Logitech (CS 10) diamond-edge cut-off machine was used to cut the rock samples into two smooth surfaces with one of the smooth surface polished to allow good bonding. The slabs were washed thoroughly with clean water to remove loose particles. Subsequently, the slabs were laced on hot plate set at 100-200°C for baking and to remove water from the samples for about 30 min. The slabs were allowed to cool to 50°C and each bonded to glass slide (75×25 mm) using Canada Balsam cement. The slabs were carefully pressed against the glass slides for about an hour to prevent the occurrence of gas bubbles in between the glass slides and the slabs employing a bonding jog on hot plate. The slides, after cooling to room temprature, were subjected to rotary grinding with different grades of carborundum powder until the rocks became grinded down to a thickness of three hundredth of a millimetre to permit light to pass through every mineral present in the rock. Petrographic study of the rocks were undertaken on the rotating stage of a polarising microscope. Mineralogical analysis was conducted by identifying minerals in the slides based on their optical properties under plane polarized light (ppl) and crossed nicols (cpl).

Modal analyses were based on thin section modal mineral analysis grid method. The remaining fresh rock samples were crushed and pulverized and the samples were packed in cellophane nylons that were properly labeled according to sample locations. Subsequently, the samples were sent to ICP-MS and XRF Laboratory, Stellenbosch University, South Africa for major element analysis by XRF, Rh Tube, 3k Watt.

Results and Discussion

Petrographic study of rocks in Orin-Ekiti was carried out through field operations and thin section examination using Petrographic microscope. Field observations revealed charnockites as the dominant rocks in the study area. Other lithotypes encountered during field operations were banded gneiss, granite gneiss and granite. The field relations indicated that the gneisses were the basement rocks into which granites and charnockites were successively emplaced. Quartz was the dominant mineral in the rocks of the study area (Table 1) indicating that the rocks were product of acidic magma crystallization (Ayodele and Ajayi, 2016). Plagioclase feldspars are next to quartz in abundance. They are found to be more prominent in the charnockitic rocks. Most of the plagioclase grains in the charnockites of Orin-Ekiti have Carlsbad twinnig (Fig. 2C1, 2C2 and 2C4) while few are albite twining (Fig. 2C3). Micro-cracks were observed in some grains of the minerals and plagioclase showing undulose extinction as well as bent lamellae (Fig. 2C2 and 2C3). Rocks are normally resistant to weathering. This resistance depends on the rock's mineral composition and porosity. The physically soft minerals are easily broken apart and crushed compare with the harder minerals. The entire weathering process is controlled by the arrangement of the mineral grains and size of a rock. Granite is highly resistant to weathering. Charnockites comprise of more pyrogenetic minerals (Hyperstene, biotite, plagioclase feldspars etc.) and these high temperature and pressure minerals are more susceptible to weathering. When the common rock-forming minerals are weathered, minerals (mostly quartz) that is especially resistant to weathering form granular materials rich in silica. The most soluble elements are transported in aqueous solutions while the immobile elements (aluminium, iron and titanium) are left to concentrate as residues. Aluminum is the earth's most abundant metallic element, making up approximately 8% of the planet's crust (Hill and Sehnka, 2006) and it is found in virtually every common rock type. The occurrence of aluminum in rocks is not in its pure form. It may occur as oxide and hydroxides, which is extracted and processed for industrial application and making it one of the most widely used metals in modern technology. Generally, the combination of these hydroxides (minerals) and other gangue minerals as a naturally occurring, heterogeneous weathering product is collectively referred to as bauxite.

Thus, the charnockites in Orin-Ekiti constitute parent rocks that could have weathered to produce the bauxite in the study area. Gow (1993) explains that bauxitization is a complex process and is practically impossible at depth below a thick overburden. He further outlined eight factors that greatly affect the formation of bauxite. These factors were amended from Harder (1952) who summarized the following factors or conditions which favor the formation of bauxite: (i) The presence of rocks with easily soluble minerals yielding residues rich in alumina; (ii) effective rock porosity, enabling easy access and free circulation of water; (iii) normal to abundant rainfall alternating with dry periods; (iv) vegetation, including bacteria, advantageously distributed; (v) available sources of appropriate solution and precipitation agencies; (vi) a tropical or at least warm climate vii) low topographic relief allowing free movement of the water table but a minimum erosion; and (viii) long quiet periods in earth history. The study area has tropical climate with abundant rainfall (average annual rainfall = 1333.2 mm) that alternates with dry seasons. The terrain is largely gentle, undulating extensively with the topographic elevation that ranged between 535-588 m above the sea level. Thus, the principal factor is the presence of rocks with easily soluble minerals yielding residues rich in alumina of which charnockites in the area have been found suitable. The modal composition of rocks in the study is presented in Table 1 and Fig. 3. The modal composition confirms the dominance of plagioclase, biotite, hyperstene and pyroxene minerals in the charnockites while the other rocks (granite, granite gneiss and banded gneiss) were dominated by quartz, microcline, amphiboles and opaque minerals. The assemblage of minerals in the rocks constitute major factor in bauxitasation of the weathered products of the rocks. It is clear that charnockites with more assemblage of pyrogenetic minerals would weather fast to produce clay that could further be leached to form bauxite. When plagioclase feldspars weathered, clay minerals are formed. The processes involved in bauxite formation are more complex than shown below, but the following example for weathering of feldspar is indicative of the overall net formation sequence (Freerange, 2017).

Step 1: Acidification of rainwater $CO_2 + H_2O \rightarrow H_2CO_3$

$$H_2CO_3 \rightarrow HCO_3^- + H^+$$
$$HCO_3^- \rightarrow CO_3^{2-} + H^+$$

Step 2: Carbonic and humic acids (from soil) react with feldspar, leaching potassium and silica and hydrating the alumino-silicate structure to form illite clay:

$$3KAlSi_3O_8 + 2H+ + 12H_2O \rightarrow KAl_3Si_3O_{10}(OH)_2 + 2K+ + 6Si(OH)_4$$

Step 3: Further leaching removes the remaining potassium, transforming illite to kaolinite:

2 KAl3Si3O10(OH)2 +2H+ + 3H2O → 3Al2Si2O5(OH)4 + 2K+

Step 4: Kaolinite is decomposed to form insoluble gibbsite and soluble hydrated silica:

$$Al_2Si_2O_5(OH)_4 + 5H_2O \rightarrow 2Al(OH)_3 + 2Si(OH)_4$$

Iron in the minerals is converted to the insoluble forms hematite and goethite. Titanium is transformed to anatase. Quartz and zircon are resistant to weathering.

The mixture of remnant minerals is called 'laterite' and is a common surface feature in tropical areas. If it is sufficiently high in alumina and low in silica, it is characterized as 'bauxite'. Laterite bauxites account for most of the world's major deposits of bauxite.

Fig. 2: Photomicrographs of Charnockites (C1-C4), Granite (G1-G2) Granite gneiss (Gg1-Gg2) and Banded Gneiss (Bg1) in transmitted light showing quartz (1), Biotite (2), Plagioclase (3), Hyperstene (4) and opaque mineral (5). Bar scale is 2 mm crossed pola

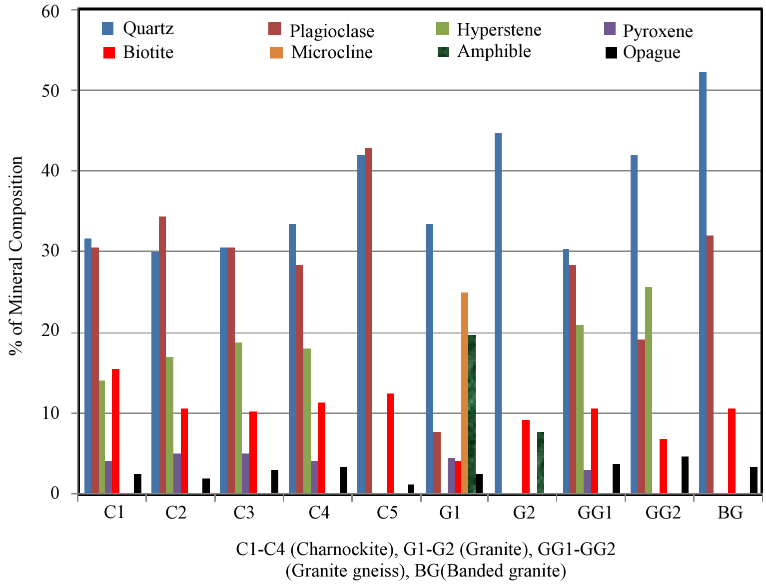

Fig. 3: Modal composition of rocks from the study area

Table 1: Modal analysis of Rocks from the study area

Minerals	Charnockite Average total count	Charnockite Modal (%)	Granite Average total count	Granite Modal (%)	Granite gneiss Average total count	Granite gneiss Modal (%)	Banded gneiss Average total count	Banded gneiss Modal (%)
Quartz	107	32	123	43	117	36	167	53
Plagioclase	106	32	25	9	88	27	102	32
Microcline	-	-	25	9	-	-	-	-
Amphibole	-	-	63	22	-	-	-	-
Hyperstene	55	17	-	-	75	23	-	-
Pyroxene	17	5	14	5	-	-	-	-
Biotite	38	11	25	9	29	9	34	11
Opaque	10	3	8	3	16	5	11	4
Total	333	100	283	100	325	100	314	100

Basement Rocks Chemistry

The major elemental composition of the basement rocks (banded gneiss, granite gneiss, granite and charnockite) are presented in Table 2. In the banded gneiss, SiO_2 concentration in mass fraction was 68.32%, Al_2O_3, Fe_2O_3 were 13.14% and 5.79% respectively while Na_2O was 2.53% and K_2O 5.41% (Table 2). Similar trend was observed in the granitic rocks with SiO_2 ranging from 62.77-70.22%, Al_2O_3 from 13.52-14.53%, Na_2O from 2.20-2.84%, K_2O from 4.18-5.98% and Fe_2O_3 from 4.08-9.27%. In the charnockites, SiO_2 ranged between 40.13% and 55.22%, Al_2O_3 from 12.98-21.66%, Fe_2O_3 from 6.28-16.44%, Na_2O from 2.59-3.51% and K_2O from 0.82-4.64%. The trend of chemical composition in the rocks of the study area with SiO_2 ranging from 40.13 to 70.22% and Al_2O_3 from 12.98-21.26% compares favourably with the work of Ayodele and Ajayi (2016) on Petrology, mineralogy and geochemistry of the Precambrian rocks around Ikere-Ekiti, Southwestern Nigeria. The SiO_2 content in the rocks ranged between 49.15 and 73.41% and Al_2O_3 from 14.70 - 15.73%.

The higher percentage of Al_2O_3 in Orin-Ekiti rocks could be responsible for Bauxitic clay formation in the area compared to Ikere-Ekiti zone. In addition, the work of Opara *et al.* (2014) on Petrology and Geochemistry of Basement Complex Rocks in Okom-Ita Area, Oban Massif, Southeastern Nigeria revealed SiO_2 content in the range of 60-75%. The high values of SiO_2>65% in the rocks of these different locations indicated magma rich in silica and of acidic nature. Comparison of the banded gneiss in the later study with Orin-Ekiti banded gneiss revealed insignificant differences in chemical composition with SiO_2 in Orin-Ekiti banded gneiss having 68.32% compare to Okom-Ita area with 66.49%. Following similar comparison, Al_2O_3 has 13.14 and 14.3% while Fe_2O_3 was 5.79% and 4.64% respectively. The formation of the rocks could be as a result of same thermo tectonic event during the Pan-African Orogeny. However, a critical examination of the Orin-Ekiti rocks bulk chemical composition showed slight difference in the trend of chemical concentrations in the charnockites. The charnockites has low silica (SiO_2), Na_2O and K_2O,

Fe_2O_3 but relatively high alkaline earth metals compared to the granitic rocks. There are no significant variations in Al_2O_3 concentrations based on rock units. In view of the observed trends in chemical composition of the rocks in the study area, formation of bauxite was not favoured. Bauxite and laterite are products of weathering from one or many types of rocks or their weathered derivatives.

Bauxitization and laterization have occurred in many rocks including sedimentary (limestone), igneous and metamorphic rocks. Therefore, bauxitization is a process that does not discriminate against source rocks but rather depends heavily on surrounding geological conditions. Rocks that are generally or moderately high in alumina content and have a relatively large percentage of soluble constituents are predisposed to laterization and bauxitization (Patterson *et al*., 1986). Charnockites are the visible outcrop close to the bauxitic clay deposit at Orin-Ekiti but other rocks (granite, granite gneiss and banded gneiss) occur in association. The rocks might all contribute to the bauxitization processes in the study area. However, reflections on the SiO_2, Al_2O_3 and Fe_2O_3 concentrations (Fig. 4) revealed charnockites as rocks with higher concentrations of Al_2O_3, Fe_2O_3 and least concentration of SiO_2 which satisfy to a reasonable extent as protolith for lateralization and bauxitization. According to Nesbitt and Young (1982), Chemical Index of Alteration (CIA) ≤ 50 signifies optimum fresh rocks value and does not allow aluminum mobility. The average Chemical Index of Alteration (CIA) of the rocks in the study area is very low (53) indicating the very low level of chemical alteration which the source rocks have suffered. However, Fig. 5 clearly revealed charnockites to have lower CIA and LOI compare to other rock units in the study area an indication of higher strength and low susceptibility to weathering. This result revealed that CIA is more applicable to regolith evaluation than fresh rocks characterization for bauxitization.

Correlation/Factor Analysis

The correlation showing interrelationship of oxides (wt%) in the Rocks of the study area is presented in Table 3. The major oxides, Na_2O, MgO, TiO_2, Fe_2O_3, Al_2O_3 and CaO are negatively correlated with SiO_2. Only, K_2O oxide showed strong positive linear trend with SiO_2 ($r = 0.93$). The negative linear trends of these oxides indicate chemical affinity that suggests their origin to have come from the same parent SiO_2 rich magma. However, the strong positive correlation of K_2O with SiO_2 implies mixing of magma rich in K_2O. Furthermore, the correlation analysis revealed negative correlation of Al_2O_3 with TiO_2 and Fe_2O_3 as against positive correlation required for bauxitization.

Rocks that could weathered to produce bauxite are expected to be rich in Al_2O_3, TiO_2 and Fe_2O_3 while low values are required for the alkalis and alkaline metals. The correlation trend indicates that the requirements for bauxite formation are not satisfied by the chemical composition of Orin-Ekiti crystalline rocks. To buttress the deductions from correlation, Factor analysis was performed on the major oxide data from the study area to foster a better understanding of their interrelationships and to explore the reduction of the experimental variables. The three components chosen all had Eigen values higher than one (the most significant one) (Golub and Van der Vorst, 2000). The three extracted factors (Table 4) explain 99.76% of data set variance in the study area. Factor 1 explains 95.92% of the total variance, factor 2 explains 2.74% while Factor 3 explains 1.10%. Factor 1 has the highest factor loadings of SiO_2, Fe_2O_3 and CaO and low factor loadings for the remaining parameters. Factor 2 has the highest (positive) factor loadings of Al_2O_3 and low (negative) factor loadings for Fe_2O_3. Factor 3 has the highest (positive) factor loadings for Al_2O_3 and low negative loading for CaO. These scenarios indicate that the factors associations strongly suggest that PC1, PC2 and PC3 may represent magma that is rich in silica. The magma assimilates other minerals as it rises from its conduit which explains why the silica is at variance with some other minerals in the melt.

Table 2: Major element of Orin Rocks (weight %)

Sample	Al_2O_3	P_2O_5	TiO_2	MgO	MNO	SiO_2	Fe_2O_3	CaO	Na_2O	K_2O	LOI	∑Con.	CIW
Ch1	13.99	4.73	4.38	4.28	0.17	40.13	15.53	12.38	2.63	0.86	-0.07	99.87	46.85
Ch2	14.03	4.63	4.85	3.46	0.20	40.22	16.44	11.75	2.66	1.07	-0.31	100.07	47.54
Ch3	13.77	4.32	4.54	4.65	0.18	40.77	15.95	11.84	2.59	0.82	-0.16	100.09	47.45
Ch4	21.26	0.80	0.81	3.82	0.09	52.1	6.28	9.14	3.51	1.33	0.15	100.62	60.33
Ch10	12.98	1.31	0.72	7.38	0.14	55.22	7.96	5.91	2.70	4.64	0.16	103.76	56.01
GR6	13.52	0.09	0.42	0.15	0.06	70.22	4.08	1.71	2.72	5.98	0.11	105.04	56.50
GR7	14.53	0.47	0.33	1.74	0.09	65.21	4.39	3.81	2.84	5.49	0.24	104.63	54.48
GG8	14.17	0.21	0.57	1.46	0.08	66.37	5.68	3.49	2.78	4.18	0.17	103.34	57.55
GG9	13.56	0.44	1.20	0.98	0.11	62.77	9.27	3.09	2.20	5.05	0.37	104.09	56.74
BGN5	13.14	0.22	0.70	0.42	0.07	68.32	5.79	2.38	2.53	5.41	0.03	104.42	49.49
Min	12.98	0.09	0.33	0.15	0.06	40.13	4.08	1.71	2.20	0.82	-0.31	99.87	46.85
Max	21.26	4.73	4.85	7.38	0.20	70.22	16.44	12.38	3.51	5.98	0.37	105.04	60.33
Mean	14.50	1.72	1.85	2.83	0.12	56.13	9.14	6.55	2.72	3.48	0.07	102.59	53.29
STDEV	2.42	1.99	1.91	2.28	0.05	12.20	4.96	4.29	0.33	2.18	0.20	2.15	4.96

Table 3: Correlation showing interrelationship of wt% oxides in the Rocks of the study area

	Al_2O_3	P_2O_5	TiO_2	MgO	MNO	SiO_2	Fe_2O_3	CaO	Na_2O	K_2O
Al_2O_3	1.00									
P_2O_5	-0.12	1.00								
TiO_2	-0.14	0.98	1.00							
MgO	0.11	0.54	0.40	1.00						
MNO	-0.18	0.94	0.91	0.66	1.00					
SiO_2	-0.15	-0.95	-0.91	-0.69	-0.93	1.00				
Fe_2O_3	-0.17	0.96	0.98	0.48	0.95	-0.92	1.00			
CaO	0.25	0.92	0.88	0.65	0.87	-0.99	0.87	1.00		
Na_2O	0.87	-0.13	-0.22	0.22	-0.22	-0.08	-0.30	0.21	1.00	
K_2O	-0.39	-0.84	-0.83	-0.55	-0.76	0.93	-0.81	-0.97	-0.29	1.00

Table 4: Factor analysis

		Components		
Parameters	PC 1	PC 2	PC 3	Communialities
Al_2O_3	-	0.73	0.37	0.67
P_2O_5	-	-	-	-
TiO_2	-	-	-	-
MgO	-	-	-0.83	0.67
MNO	-	-	-	
SiO_2	-0.86	-	-	0.74
Fe_2O_3	0.33	-0.54	0.23	0.45
CaO	0.30	-	-	-
Na_2O	-	-	-	
K_2O	-	-	-	
Variance (%)	95.92	2.74	1.10	
CVariance (%)	95.92	98.66	99.76	
Range of assigned factor	-0.86-+0.33	-0.54-+0.73	-0.83- +0.37	
Loading extracted factor	95.92-95.92	2.74-98.66	1.10-99.76	
Controlling variable	SiO_2, Fe_2O_3 and CaO	Al_2O_3 and Fe_2O_3	Al_2O_3, Mgo and Fe_2O_3	

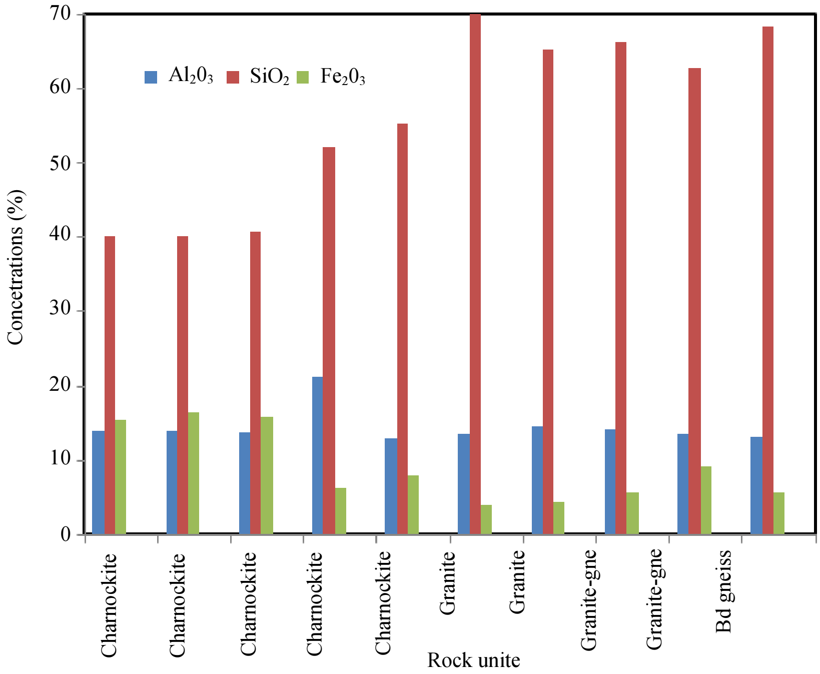

Fig. 4: Diagram indicating SiO_2, Al_2O_3 and Fe_2O_3 concentrations in rocks of the study area

Orin-Ekiti Crystalline Rocks Classification and Provenance Evaluation

General classification of rocks employing SiO_2 content indicates that rocks with more than 65% silica are called felsic; those with between 55 and 65% silica are intermediate; those with between 45 and 55% silica are mafic while those with SiO_2<45% are ultramafic. The rocks in the study area are classified as Felsic (granite, granite gneiss and banded gneiss) and ultramafic (charnockites). These two groups can further be categorized into suitability for formation of bauxite based on chemical composition. Rocks that are susceptible to bauxitization must be relatively poor in silica content, rich in Al_2O_3, TiO_2 and poor in CaO, MgO and the alkalis. Charnockites appear more favourable than any other rocks for formation of bauxite in the study area.

To further classify the rocks and evaluate their provenance, the geochemical data of the oxides (wt%) were plotted in variation/discriminatory diagrams as indicated in Fig. 6 to 9. The plot of Na_2O + K_2O-CaO versus SiO_2 diagram after Frost *et al*. (2001) (Fig. 6) categorized granites, granite gneiss and banded gneiss rock units into the calcic-alkali category signifying availability of quartz in the rock units. In addition, the plot of K_2O versus SiO_2 after Ewart (1982) (Fig. 7), showed virtually that charnockites fell into calc-alkaline series indicating that the rocks have high ratios of large ion lithophile elements (Sheth *et al*., 2010). The granite and granite gneiss fell into alkaline series indicating higher concentration of alkalis that cannot be accommodated in feldspars alone. The excess alkalis appear as feldspathoids, sodic pyroxene, sodic amphiboles and other alkalis rich phases (Fitton and Upton, 1987). The calcic rocks contain more ferromagnesian minerals that can easily weathered and be leached off while the immobile elements (Al_2O_3, TiO_2 and Fe_2O_3) could concentrate to form bauxite indicating that the charnockites are more favourable for bauxitization. Figure 7, 8 and 9 clarified that the Basement rocks from Orin are of magmatic origin in line with early works on the Basement rocks of Southwestern Nigeria (Rahaman and Ocan, 1978; Ademeso and Adeyeye, 2011).

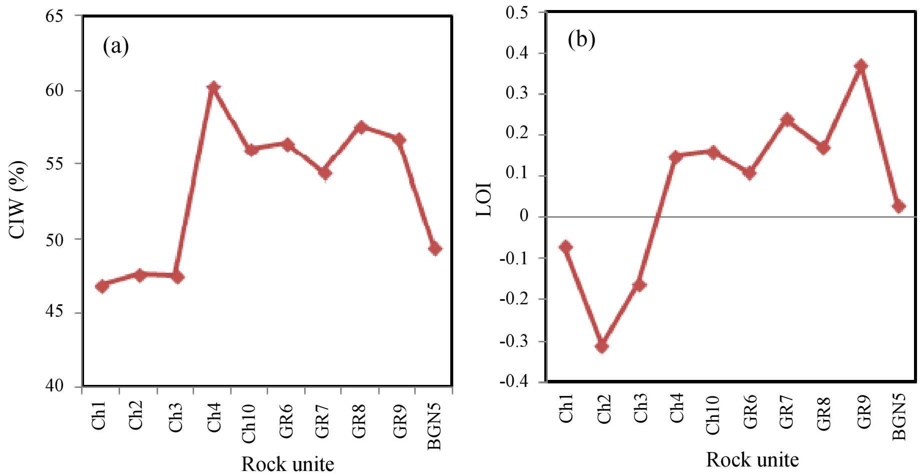

Fig. 5: Cross plots of CIW and LOI vs. SiO_2

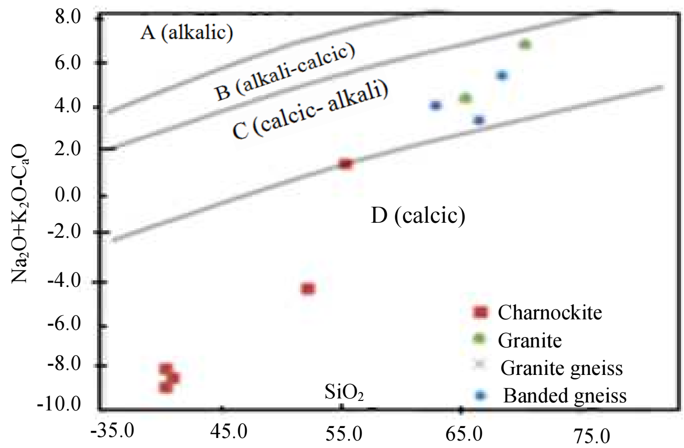

Fig. 6: Na_2O+K_2O-CaO vs SiO_2 diagram (Frost *et al*., 2001)

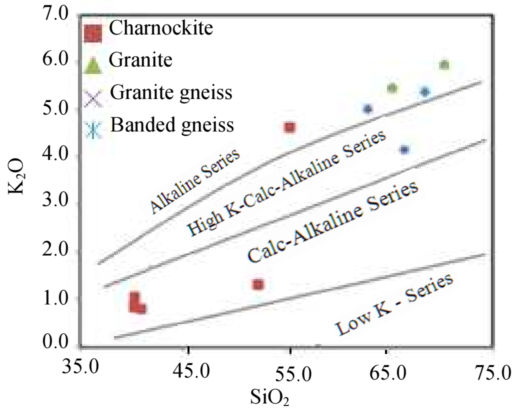

Fig. 7: SiO_2 versus K_2O (Ewart, 1982)

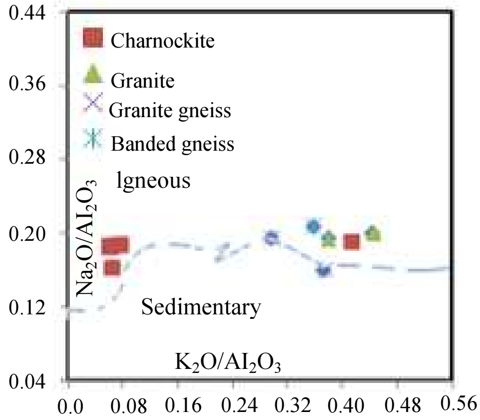

Fig. 8: K_2O/Al_2O_3 vs. Na_2O/Al_2O_3 (Garrels and Mackenzie, 1971)

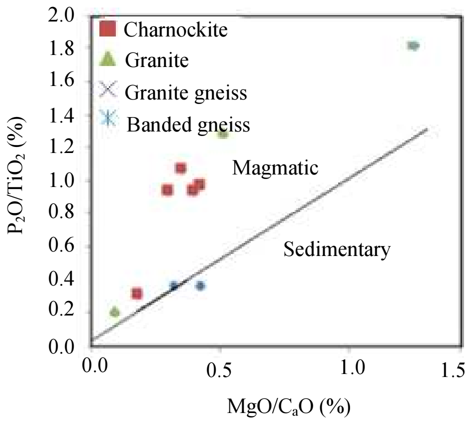

Fig. 9: MgO/CaO versus P_2O_5/TiO_2 diagram (Werner, 1987)

Conclusion

Petrography and Geochemistry of Orin-Ekiti Basement rocks, Southwestern Nigeria revealed charnockites as the dominant rock in the study area with other lithotypes including granite, granite gneiss and banded gneiss. The rocks are product of acidic magma as quartz was the dominant mineral. Based on silica content, the rocks in this study are classified as felsic (granite, granite gneiss and banded gneiss) with SiO_2>65% and ultramafic (charnockites) with SiO_2<45%. Charnockites with low SiO_2, high Al_2O_3 and TiO_2 compared to other rocks in the study area is considered more favourable to form bauxite during weathering. The rocks in the study area are classified into calcic-alkali and calcic groups with igneous protolith.

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Author Contributions

Abel Ojo Talabi: He designed the study, participated in all the stages of the paper. He is the corresponding author responsible for all correspondences.

Akin Ojo Oyinloye: This Author participated in the field work and provided leadership role in all the stages of this manuscript.

Olusola Amos Olaolorun: He participated in the field work, supervised cutting and thin section preparation and participated actively in the manuscript preparation.

Romanus Ayoola Obasi and Akinola Bolaji Eluwole: He participated in the field work, carried microscopic identification of minerals and established modal composition. He was active at all stages of the manuscript.

Olajide Femi Adebayo and Oladimeji Lawrence Ademilua: He participated in the field work, carried out some graphical plots and edited the manuscript. He was active at all stages of the manuscript.

Conflict of Interest

There is no conflict of interest from any of the Authors of this Manuscript.

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