Odewumi and Olarewaju, J Geol Geosci 2013, 2:1
DOI: 10.4172/2381-8719.1000109

Journal of Geology & Geosciences
ISSN: 2381-8719

Research Article

Petrogenesis and Geotectonic Settings of the Granitic Rocks of Idofin-osi-eruku Area, Southwestern Nigeria using Trace Element and Rare Earth Element Geochemistry

S.C. Odewumi[1]* and V.O. Olarewaju[2]

[1]Department of Science Laboratory Technology, University of Jos, P.M.B. 2084, Jos, Nigeria
[2]Department of Geology, Obafemi Awolowo University, Ile Ife, Nigeria

Abstract

The Idofin-Osi-Eruku area occurs in the south-eastern margin of the southwestern sector of the Nigerian Basement Complex. Granitic rocks and early gneiss samples were studied geologically and geochemically using ICP-MS. The study focuses on the trace elements and rare earth elements geochemistry in determining the geochemical characteristics and geotectonic processes of formation of the granitic rocks. Geologically, Idofin-Osi-Eruku area is underlain by early gneiss, quartzite and marble which have been intruded by granite gneiss, porphyritic granite and fine to medium-grained granite of probable Pan-African (ca. 600Ma) age.

Geochemical data indicate that the granitic rocks are Fe-rich potassic granites. The varying ratios of the incompatible elements of Rb/Sr ratios (0.664-1.388) in porphyritic granite, (0.338-2.390) in the fine to medium-grained granite and (0.593-1.509) in granite gneiss are higher than Rb/Sr ratio (0.029) in the early gneiss. Also, Ba/Sr ratios (2.815-5.424) in porphyritic granite, (3.463-4.636) in fine to-medium grained granite and (2.132-4.734) in granite gneiss are higher than Ba/Sr ratio (0.912) in the early gneiss. And Ba/Rb ratios (2.486-6.192) in porphyritic granite, (1.473-1.520) in the fine to-medium grained granite and (3.183-3.595) in the granite gneiss are lower than Ba/Rb ratio (31.02) in the early gneiss. Higher ratios of Rb/Sr and Ba/Sr, and lower ratio of Ba/Rb in the granitic rocks than the early gneiss indicate high fractionation associated with magmatic differentiation.

The granite rocks have fractionated Rare-Earth Elements (REE) patterns characterized by enrichment in the Light Rare-Earth Elements (LREE) which is confirmed by high values of the normalized ratios of La/Yb, Ce/Yb and La/Sm, with negative europium anomalies and varying degrees of Heavy Rare-Earth Elements (HREE) depletion which is typical of the crust and also of calc-alkaline rocks. Based on the overall abundances of Rare-Earth Elements (REE), the similarities in the Rare-Earth Elements (REE) patterns of the granitic rocks suggest the same origin. Geotectonically, the granite gneiss, fine to medium-grained granite and porphyritic granite plot as syncollisional and volcanic arc granites. The granitic rocks are products of volcanic arc magmatism emplaced in the late phase of the Pan-African Orogeny.

Keywords: Syncollisional; Volcanic arc; Calc-alkaline; Shoshonitic; Crustal

Introduction

The Idofin-Osi-Eruku area forms part of the southeastern margin of the southwestern sector of the Nigerian Basement Complex (Figure 1). This Basement Complex comprises of gneisses and migmatites with supracrustal relics, which have yielded Archean (c. 2700Ma) and Proterozoic (c.2000Ma) ages [1,2]. Rock types in the Nigerian Basement Complex include a variety of migmatitic gneisses, quartzites, migmatized paragneisses, paraschists and orthogneisses with minor intercalations of metamorphosed mafic-ultramafic bodies as well as meta-carbonates. The migmatitic rocks include both high-grade migmatites and injection-type migmatites. These metamorphic rocks form the host into which the intrusive granitoids i.e. Older Granites were emplaced [3].

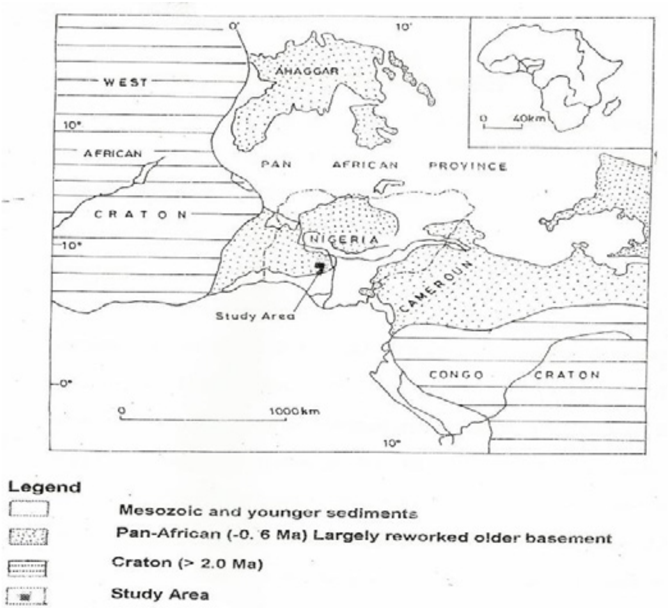

Figure 1: Location of the Nigerian sector of Pan African Province of West Africa (Modified after Boher et al [24].

Variations in the abundance of trace elements, rare earth elements and their distribution patterns are useful in tracing the evolution of granitic and basaltic rocks. These also provide information on whether the granitic rocks are derived from magmatic differentiation and on the degree of fractionation [4,5]. Previous work in Osi area [6] indicated that the granite gneiss and porphyritic granite were emplaced in relation to different cycles of deformation and the earlier granite gneiss was at a relatively deeper crustal level than the later porphyritic granite cycle. There is very limited documentation on the geochemical

***Corresponding author:** S.C. Odewumi, Department of Science Laboratory Technology, University of Jos, P.M.B. 2084, Jos, Nigeria, Tel: +2348034991835; E-mail: sholaodewumi@yahoo.com

Received December 06, 2012; **Accepted** December 20, 2012; **Published** December 24, 2012

Citation: Odewumi SC, Olarewaju VO (2013) Petrogenesis and Geotectonic Settings of the Granitic Rocks of Idofin-osi-eruku Area, Southwestern Nigeria using Trace Element and Rare Earth Element Geochemistry. J Geol Geosci 2: 109. doi:10.4172/2381-8719.1000109

Citation: Odewumi SC, Olarewaju VO (2013) Petrogenesis and Geotectonic Settings of the Granitic Rocks of Idofin-osi-eruku Area, Southwestern Nigeria using Trace Element and Rare Earth Element Geochemistry. J Geol Geosci 2: 109. doi:10.4172/2381-8719.1000109

characteristics, granitic classifications, genetic and tectonic origin of the granitic rocks in Idofin-Osi-Eruku area. The present study focuses on the trace elements and rare earth elements geochemistry with the aim of determining the geochemical characteristics and geotectonic processes of formation of the granitic rocks.

Geological settings

The Idofin-Osi-Eruku area is underlain by crystalline rocks. Six major lithological units have been identified in the area and they include early gneiss, marble, quartzite, granite gneiss, porphyritic granite and fine to medium-grained granite (Figure 2). The early gneiss is generally dark grey in colour. It is a medium-grained rock and outcrops as low-lying rock bodies. Banding in the gneiss varies in thickness and persistent for about 8 meters; the thickness of individual bands vary from about 5 millimeters to 2 centimeters. The dark bands in the early gneiss are rich in biotite while light coloured bands are made up of quartz and plagioclase feldspar. Narrow ductile and brittle-ductile shear zones are also observed in the early gneiss. The early gneiss is the country rock into which the other rock types especially granites was emplaced. Quartz forms rounded inclusions in oligoclase crystals and tend to be interstitial in the quartz-feldspar mosaic, also there is myrmekitic intergrowth of quartz and plagioclase feldspar. Oligoclase with An_{25-50} composition forms anhedral crystal showing albite twinning and combination of albite and Carlsbad twinning.

Accessory minerals include epidote and sericite which were formed by late stage alteration of plagioclase feldspar. Marble occurs as well-exposed outcrops in Okunrun and Okoloke areas and as well as low-lying lensoid bodies within the granitic gneiss about two kilometers west of Okunrun. The marble is whitish to light grey in colour and has a medium-grained texture. The mineralogy of Okunrun marble is essentially calcite and tremolite, the calcite occurs as subhedral to euhedral crystals, exhibiting hour-glass extinction. The Okoloke marble consists mainly of large interlocking anhedral grains of calcite with graphite inclusions within the calcite crystals. While quartzites are exposed as continuous north-south trending outcrops and occurs as ridges in the southwest of Osi area. The quartzite bodies are locally fractured and quartz veins of varying width occur as late intrusive into the quartzites. Cross-cutting joints are also observed in the quartzite. Quartzite shows a medium-grained texture and the mineralogy is essentially quartz which is colourless and shows no cleavage. The granite gneisses are generally well exposed usually occurring as isolated domes and low ridges often strewn with boulders in the northeast and southeast part of the study area. The granite gneiss is generally a medium-grained rock and the mineralogy includes quartz, K-feldspar, plagioclase and minor biotite. Locally, the alignment of light and dark coloured minerals marks the foliation and the preferred platy parallelism of crystals of biotite defines the foliation. Sericite and epidote were formed from late stage alteration of plagioclase and they constitute the accessory minerals. Oligoclase with An_{15} forms anhedral crystal showing the combination of albite and Carlsbad twinning and occurs in a mosaic with quartz. Subidiomorphic microcline laths are usually scattered among the other components and an indistinct porphyroblastic texture is always present.

Porphyritic granite outcrops in the eastern and western part of the study area within the early gneiss and granitic gneiss. It is characterized by feldspathic phenocrysts of microcline that vary in size from one location to the other within groundmass of quartz, plagioclase and biotite. There is myrmekitic intergrowth of quartz and plagioclase. The phenocrysts are microcline crystals with pronounced poikilitic texture. While the fine to medium-grained granite outcrops in the southern part around C.A.C. Prayer Mountain Odo-Owa as inselbergs. It is light grey in colour, massive and has a medium-grained texture. Pegmatites occur as intrusions in the fine to medium-grained granite. Quartz occupies interstitial positions between biotite, microcline and plagioclase. The plagioclase exhibit albite twinning and microcline crystals are subhedral showing the characteristics cross-hatched twinning.

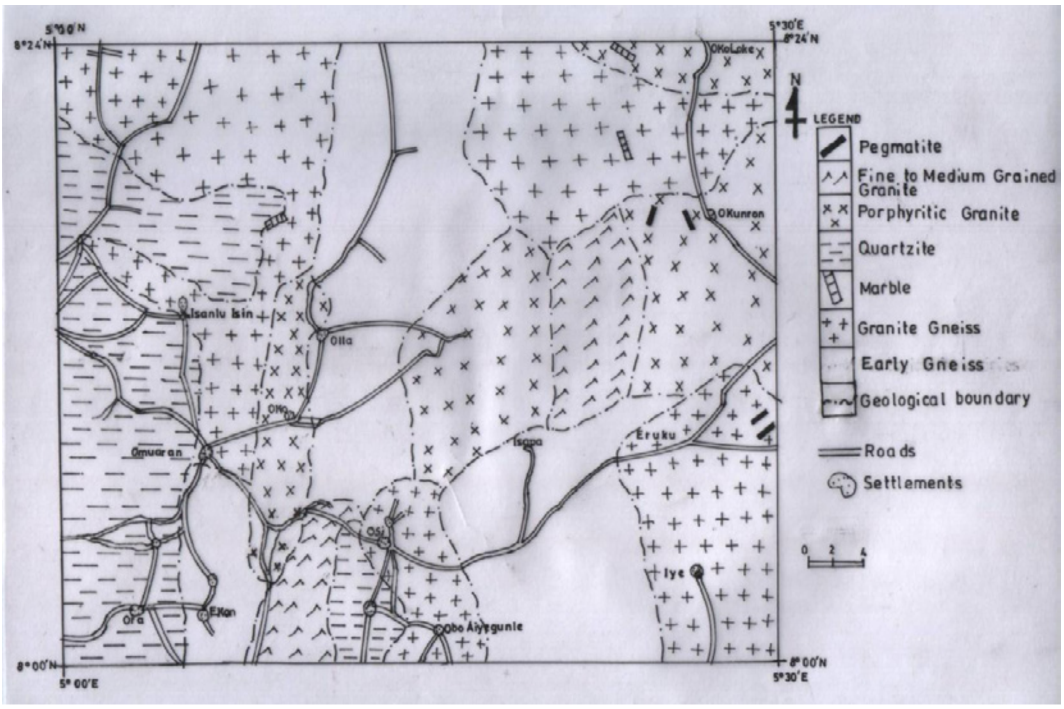

Figure 2: Geological map of Idofin-Osi-Eruku area.

Analytical Methods

The whole rock geochemical analyses comprising major oxides, trace elements and rare earth elements of twelve samples of granitic rocks and one sample of early gneiss were carried out at Activation Laboratory, Ontario, Canada. All the rocks samples were ground with mortar and pestle. The samples were analyzed for major oxides (SiO_2, TiO_2, Al_2O_3, Fe_2O_{3T}, MnO, MgO, CaO, Na_2O, K_2O, P_2O_5, Cr_2O_3, tot/C and tot/S); trace elements (Ag, As, Au, Ba, Be, Bi, Cd, Co, Cu, Cs, Ga, Hf, Hg, Mo, Nb, Pb, Rb, Sb, Se, Sn, Sr, Ta, Th, U, V, W, Zn, Zr and Y) and rare earth elements (La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb and Lu) using a Lithium metaborate/tetraborate fusion and nitric acid digestion of 0.2g of each sample.

The sample is typically introduced into the ICP plasma as an aerosol, by aspirating the dissolved solid sample into a nebulizer. The sample is completely desolvated and the elements in the aerosol are converted first into gaseous atoms and then ionized towards the end of the plasma. The elements in the samples are converted into ions, they are then brought into the mass spectrometer *via* the interface cones. The interface region in the ICP-MS transmits the ions traveling in the argon sample stream at atmospheric pressure (1-2 torr) into the low pressure region of the mass spectrometer ($<1\times10^{-5}$ torr). The ions from the ICP source are then focused by the electrostatic lenses in the system and the ions enter the mass spectrometer, they are separated by their mass-to-charge ratio. The quadrupole mass filter separate up to 2400 amu (atomic mass units) per second and is often considered to have simultaneous multi-elemental analysis. Typical quadrupole mass spectrometers used in ICP-MS have resolutions between 0.7-1.0 amu and was used for the geochemical analysis of the rock samples from the area [7].

Results

The whole rock geochemical data comprising major oxides (Table 1) and rare earth elements compositions of the twelve representative granitic rocks samples and one early gneiss sample analyzed from Idofin-Osi-Eruku area are presented in table 2. Table 3 shows the trace element concentrations of the granitic rocks and early gneiss of the area and average granite and crust [8] which have been included for comparison. Considering the major oxides, SiO_2 varies from 64.65 to 73.34%, Al_2O_3, Fe_2O_{3T}, CaO, MgO ranges between 13.22 and 16.22%. 1.64 and 5.35%, 0.85 and 4.26% and, 0.30 and 1.89% respectively. While Na_2O, K_2O and TiO_2 ranges between 2.56 and 4.38%, 0.75 and 6.87% and, 0.20 and 0.71% respectively. The fine to medium-grained granite contains the highest percentage of SiO_2 than the porphyritic granite and granite gneiss. The Al_2O_3 values of the granite gneiss is higher than that of porphyritic granite and fine to medium- grained granite, the Fe_2O_{3T} content of the fine to medium-grained granite is relatively lower than that of porphyritic granite and granite gneiss while the MgO and CaO content of the granite gneiss is higher than that of fine to medium-grained granite and porphyritic granite.

The values of High Field Strength Elements (HFSE) (U, Be, Sn, Mo, W, Zr, Nb, Hf, Ta) and Large Ion Lithophile Elements (LILE) (Rb, Cs, Ba, Pb, Sr, Th and REE) of the granitic rocks compared well with the values of average granite and crust [8]. The enrichment of some of the HFSE like Nb, Hf and Ta in the granitic rocks suggests volatile concentrations during the evolution of granites. Of all the trace elements Rb and Th show abnormally very high values compared to average granite and crust. The values of Rb (155.9 to 289.1 ppm) and Th (21 to 76.2ppm) are higher in the granitic rocks than in the early gneiss with Rb (18.7 ppm) and Th (6.6 ppm) respectively. The high values of Hf in the granitic rocks indicate presence of zircon in the mineralogical compositions of the granitic rocks because zircon is the source of Hf [9].

The Rb/Sr ratio ranges from 0.664 to 1.388 in the porphyritic granite, 0.338 to 2.390 in fine to medium-grained granite, and 0.593 to 1.509 in granite gneiss. The Ba/Sr ratio ranges from 2.815 to 5.424 in porphyritic granite, 3.463 to 4.636 in fine to medium-grained granite and 2.132 to 4.734 in granite gneiss. The Ba/Rb ratio ranges from 2.486 to 6.192 in porphyritic granite, 1.473 to 1.520 in medium grained granite and 3.183 to 3.595 in granite gneiss. The limited variation in the incompatible element ratios of Rb/Sr, Ba/Sr and Ba/Rb for each group of granitic rocks suggest partial melting.

Discussion

In the SiO_2 *vs.* Total Alkali Diagram (TAD) (Figure 3) [10], all the granitic rocks plot in the calc-alkaline field. In the K_2O versus SiO_2 diagram [11] as shown in figure 4, the granite gneiss plot predominantly in high K-Calc-alkaline and medium K-Calc-alkaline fields while porphyritic granite and fine to medium-grained granite plot in the high K-Calc-alkaline and shoshonitic fields. In the plot of $FeO_{total}/(FeO_{total+MgO})$ against SiO_2 [12] (Figure 5), the granitic rocks of the area plot in the magnesian and ferroan (Fe-enriched) fields. The

Rock types	Porphyritic granite					Fine to Medium grained granite			Granite gneiss				Early gneiss
Major Oxides	SC1	SC 2	SC 3	SC 4	SC 5	SC 6	SC 7	SC 8	SC 9	SC 10	SC 11	SC 12	SC 13
SiO_2	71.64	65.64	70.27	67.54	72.89	72.96	73.34	69.99	64.65	65.53	72.8	72.49	70.41
Al_2O_3	14.09	15.68	15.53	15.71	13.22	13.86	13.65	14.98	16.22	14.9	14.29	14.98	14.82
Fe_2O_3	2.33	3.81	1.78	3.97	3.43	2.09	1.89	2.54	5.1	5.35	1.64	1.69	3.17
MgO	0.4	0.82	0.54	0.54	0.43	0.39	0.39	0.51	1.89	1.68	0.30	0.30	0.17
CaO	1.54	2.37	1.34	1.31	1.39	1.34	1.34	1.68	4.26	3.98	0.85	0.87	3.32
Na_2O	2.8	2.88	4.38	2.56	2.86	3.2	3.23	3.24	3.37	3.55	3.33	3.38	4.81
K_2O	5.88	6.87	5.08	6.74	0.75	5.49	5.29	5.76	3.06	3.27	5.29	5.44	1.62
TiO_2	0.31	0.71	0.25	0.48	0.36	0.28	0.29	0.33	0.58	0.59	0.20	0.22	0.33
P_2O_5	0.08	0.24	0.08	0.24	0.19	0.09	0.08	0.12	0.14	0.17	0.07	0.07	0.13
MnO	0.03	0.05	0.03	0.05	0.05	0.03	0.03	0.02	0.08	0.09	0.03	0.04	0.06
Cr_2O_3	<0.002	<0.002	<0.002	0.80	0.30	<0.002	<0.002	0.50	0.009	0.005	0.002	0.002	0.50
TOT/C	<0.02	0.02	0.02	0.03	0.03	0.03	0.04	0.06	0.04	0.05	0.03	0.03	n.d
TOT/S	<0.02	<0.02	<0.02	0.01	0.01	<0.02	<0.02	0.01	<0.02	0.02	0.01	0.01	n.d
Sum	99.82	99.61	99.81	99.80	99.91	99.83	99.85	99.74	99.8	99.8	99.93	99.73	99.88

Table 1: Major oxides compositions (wt%) of the granitic rocks and early gneiss of the area.

Rock types	Porphyritic granite					Fine to Medium grained granite			Granite gneiss				Early gneiss
REE	SC1	SC 2	SC 3	SC 4	SC 5	SC 6	SC 7	SC 8	SC 9	SC 10	SC 11	SC 12	SC 13
La	101.9	170.6	33.3	218.8	111.4	62.6	13.4	100.5	53.9	69.6	57.6	67.6	29.2
Ce	156.4	310.4	57.8	241.9	289.8	132.9	19.2	186.4	95.4	127.7	100.5	113.2	58.2
Pr	18.9	31.37	6.12	42	25.7	14.45	2.56	16.7	10.2	13.8	10.7	13	6.4
Nd	63.6	105.1	21.6	169.9	95.9	57.2	9.8	56.6	35.5	49.1	38.81	38	25.6
Sm	7.85	13.11	2.95	28.2	17.7	10.52	1.88	7.6	6.69	8.09	6	7.8	4.9
Eu	1.2	2.15	0.79	1.6	0.6	2.01	0.43	0.9	1.31	1.44	0.8	0.7	1.1
Gd	5.04	9.11	2.22	19.1	9.8	9.05	1.61	2.8	6.35	7.13	4.2	4.7	3.8
Tb	0.65	1.16	0.25	2.1	1.4	1.59	0.23	0.3	1.14	1.12	0.6	0.6	0.4
Dy	3.24	5.98	1.08	10.4	5.9	9.04	1.17	1.5	7.33	7.09	3.8	4.2	2.6
Ho	0.55	1	0.17	1.7	0.8	1.75	0.16	0.2	1.57	1.34	0.6	0.7	0.5
Er	1.41	2.85	0.49	3.6	1.4	5.08	0.41	0.6	5.08	4	1.6	1.7	1.3
Tm	0.2	0.43	0.09	0.5	0.2	0.96	0.05	0.1	0.86	0.67	0.3	0.3	0.2
Yb	1.23	2.53	0.79	2.8	1	7.2	0.25	0.60	6.11	4.12	1.7	1.8	1.3
Lu	0.16	0.39	0.08	0.3	0.1	0.93	0.04	0.1	0.8	0.62	0.2	0.2	0.2
ΣLREE	348.65	630.6	121.77	700.8	540.5	277.7	46.84	367.8	201.7	268.3	213.6	239.6	124.3
ΣHREE	13.68	25.6	5.96	42.1	21.2	37.61	4.35	7.1	30.55	27.53	13.80	14.9	11.40
ΣLREE/ΣHREE	25.49	24.63	20.43	16.65	25.49	7.38	10.77	51.81	6.60	9.75	15.48	16.08	10.90
ΣREE	362.33	656.2	127.73	742.9	561.7	315.3	51.19	374.9	232.2	295.8	227.4	254.5	135.7
La_N/Yb_N	55.40	45.09	28.19	52.37	74.42	5.82	35.7	111.9	5.89	11.32	22.65	25.12	15.03
Ce_N/Yb_N	32.34	31.2	18.6	22.02	73.63	4.70	19.5	78.94	3.97	7.89	15.03	16.00	11.39
La_N/Sm_N	8.00	8.03	6.98	4.79	3.88	3.67	4.40	8.17	4.96	5.30	5.92	5.35	3.69

Table 2: Rare earth element concentrations (ppm) of the granitic rocks and early gneiss of the area.

Rock types	Porphyritic granite					Fine to Medium grained granite			Granite gneiss				Early gneiss	Ave. granite	Ave crust
Trace	SC1	SC2	SC3	SC4	SC5	SC6	SC7	SC8	SC9	SC10	SC11	SC12	SC13	14	15
Ag	0.1	<0.1	<0.1	<20	<20	<0.1	<0.1	37	<0.1	<0.1	2	1.8	<20	0.04	0.07
As	<0.5	<0.5	<0.5	0.80	0.70	<0.5	<0.5	1.4	<0.5	<0.5	0.7	1	0.9	1.5	1.8
Au	<0.5	<0.5	<0.5	<10	<10	<0.5	<0.5	<0.1	<0.5	<0.5	<0.1	<0.1	<0.1	n.d	n.d
Ba	895	1790	926	1190	504	568	557	237	686	659	737	748	580	600	425
Be	2	2	7	1.0	1.0	5	6	2	6	3	4	5	1	50.1	0.17
Bi	<0.1	<0.1	<0.1	<.04	<.04	<0.1	<0.1	<.04	<0.1	<0.1	0.12	0.13	<.04	0.1	0.17
Cd	<0.1	<0.1	<0.1	0.11	0.06	<0.1	<0.1	0.2	<0.1	<0.1	0.16	0.2	0.19	n.d	n.d
Co	3.4	7.1	2.7	6.1	4.5	2.0	2.3	3.6	13.1	12.3	2.4	2.4	5.2	1	25
Cu	0.8	9.5	16	21.3	7.09	5.7	5.8	14.97	1.5	0.6	5.92	5.7	5.85	10	55
Cs	2	1.5	6.3	0.9	1.1	1.6	1.4	1	3.7	3.2	4.9	4.9	0.3	5	3
Ga	19	21	26.1	22.1	20.09	20.5	20.3	19.62	22.5	18.9	20.94	21.62	17.39	18	15
Hf	6.6	11.1	3.6	0.47	2.01	8.9	7.9	4.63	6.2	6.8	2	2.1	0.63	4	3
Hg	0.01	<0.01	0.01	n.d	n.d	0.01	<0.01	n.d	<0.01	<0.01	n.d	n.d	n.d	n.d	n.d
Mo	0.2	0.4	0.01	3.12	0.46	0.3	0.4	1.64	0.2	0.7	0.24	0.24	526	2	1.5
Nb	13.3	28.8	6	16.2	17.01	24.4	24.4	9.95	20.6	16.5	24.12	23.8	6.6	20	20
Pb	5.6	7.6	12.9	49.1	39.79	47.9	12.1	35.91	6.2	4	36.99	38.6	13.54	20	12.5
Rb	278	289.1	218.	261.	202.7	386	373.1	155.9	190.8	200.1	240	235	18.7	150	90
Sb	<0.1	<0.1	<0.1	0.04	<.02	<0.1	<0.1	0.05	<0.1	<0.1	0.06	0.05	0.03	0.2	0.2
Se	<0.5	<0.5	<0.5	n.d	n.d	<0.5	<0.5	n.d	n.d	<0.5	<0.5	n.d	n.d	n.d	n.d
Sn	2	3	5	0.5	0.8	3	3	1.8	7	5	2	2.1	1.7	3	2
Sr	204	330	329	221	146	164	156.1	461	321.8	269.8	159	158	636	285	375
Ta	0.8	1.6	0.7	0.4	0.4	1.6	1.2	0.4	2.2	1.9	2.5	2.6	0.4	3.5	2
Th	38.4	58.2	22.7	43.8	87.7	68.4	76.2	27.4	25.6	32.6	21	22.1	6.6	17	10
U	10.6	3.6	4.3	0.9	2.6	12.8	13.3	1.6	2.2	6.5	3.4	3.6	0.3	4.8	2.7
V	22	41	30	19	15	20	17	18	67	67	12	12	30	20	135
W	<0.5	<0.5	<0.5	0.1	<0.1	<0.5	<0.5	0.2	<0.5	<0.5	0.2	0.4	0.1	2	1.5
Zn	36	49	44	230.	131.2	54	43	231.7	59	42	205.9	209.9	188.4	40	70
Zr	219	429.3	132.	15	57.8	305.	259.3	182.6	218.3	214.6	43.4	49.4	16	180	165
Y	15.7	28.2	6.4	50.3	20.6	14.6	13.8	7	45.4	37.9	18.7	21.2	13.3	40	30
Rb/Sr	1.36	0.88	0.66	1.18	1.39	2.35	2.39	0.34	0.59	0.74	1.51	1.48	0.029	0.53	0.24
BaRb	3.22	6.19	4.24	4.55	2.49	1.47	1.49	1.52	3.60	3.29	3.07	3.18	31.02	4	4.72
Ba/Sr	4.39	5.42	2.82	5.39	3.45	3.46	3.57	4.64	2.13	2.44	4.64	4.73	0.91	2.11	1.13

SC 1-5: Porphyritic granite; **SC** 6-8: Medium grained granite; **SC** 9-12: Granite Gneiss; **SC**13-early gneiss; 14-Average Granite (Taylor [8]); 15-Average Crust (Taylor [8]). n.d=not detected.

Table 3: Trace elements concentrations (ppm) of the granitic rocks and early gneiss

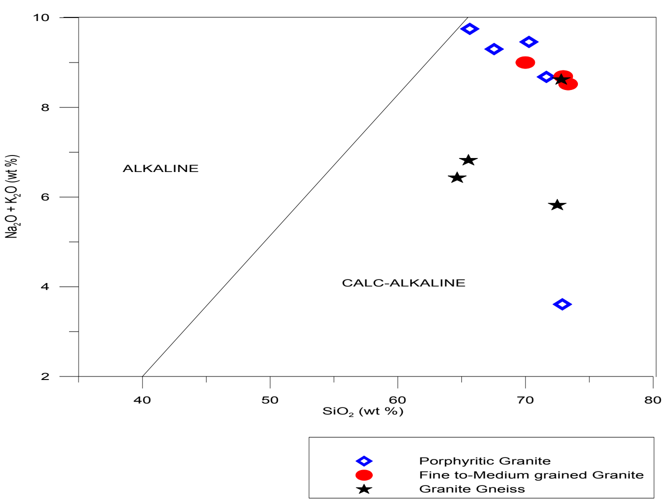

Figure 3: Total alkali versus silica oxide diagram for the granitic rocks of Idofin-Osi-Eruku area (adopted from Le Maitre [10].

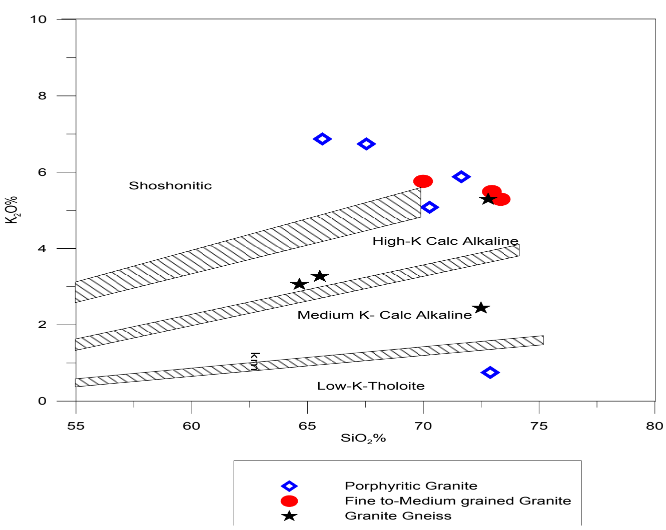

Figure 4: K_2O versus SiO_2 diagram for the granitic rocks of Idofin-Osi-Eruku area . Pearce et al. [15].

SiO_2 contents as well as the Fe-enrichment increase from granite gneiss through the porphyritic granite to, fine to medium-grained granite. Ferroan granitic rocks are closely associated with conditions of limited availability of H_2O and low oxygen fugacity during melting [12]. The magma is also likely to undergo extensive fractionation towards iron-rich compositions [13] with the early crystallization of anhydrous silicates.

In Na_2O+K_2O-CaO *vs.* SiO_2 diagram [12] (Figure 6), the granite gneiss plot in the alkali-calcic and calc-alkalic fields, the porphyritic granite plot in the alkali, alkali-calcic and calcic fields, while fine to medium-grained granite plot in alkali-calcic field. In the $Al_2O_3/(Na_2O+K_2O)$ *vs.* $Al_2O_3/(CaO-Na_2O+K_2O)$ (molecular) diagram (Figure 7) [14], the granitic rocks plot predominantly in the peraluminous field. Variation in the Modified Alkali-Lime Index (MALI) can be caused by either the source region or differentiation history of magma. The alkalic to calcic nature of the granitic rocks seem to be related to the source regions of their magmas because cordilleran (volcanic arc) granitoids became progressively more potassic and alkalic away from the subduction zone. Also peraluminous leucogranite can either be magnesian or ferroan or have a MALI that range from calcic to alkali [12]. This is similar to the granitic rocks in Idofin-Osi-Eruku area that are predominantly peraluminous, magnesian to ferroan granites and have MALI range from calcic to alkalic.

In the Rb versus SiO_2 as shown in (Figure 8) [15], discrimination diagram for tectonic setting, the porphyritic granite and fine to medium-grained granite plot in the syn-collisional granite field while granite gneiss plot in the syn-collisional and Volcanic arc granite fields. Also in the Rb versus Y+Nb diagram as shown in figure 9 [15], the fine to medium-grained granite, porphyritic granite and granite gneiss plot in the syn-collisional and Volcanic arc granite fields. The granitic rocks of the area plot in the syncollisional and volcanic arc granite fields and were products of volcanic arc magmatism probably associated with the late stages of Pan African Orogenic event since post collisional granites

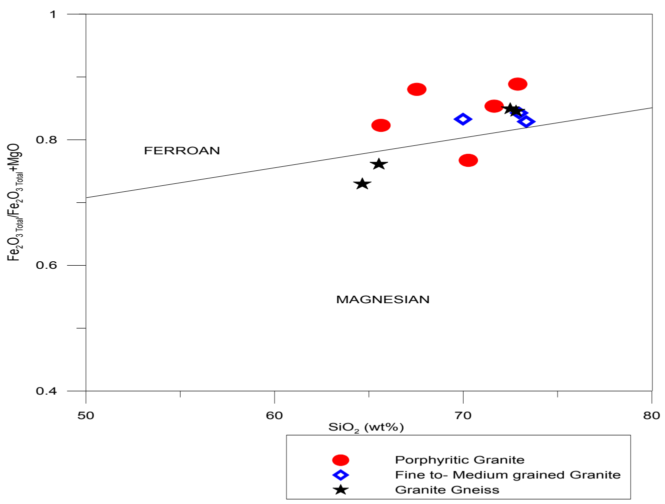

Figure 5: $FeO_{total}/(FeO_{total}+MgO)$ versus SiO_2 plot diagram for the granitic rocks of Idofin-Osi-Eruku area (after Frost et al [12].

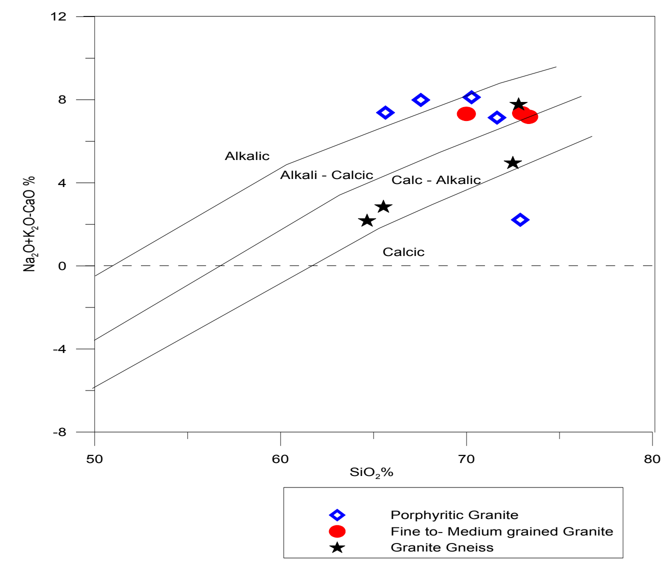

Figure 6: Na_2O+K_2O-CaO versus SiO_2 for the granitic rocks of Idofin-Osi-Eruku area (after Frost et al [12]).

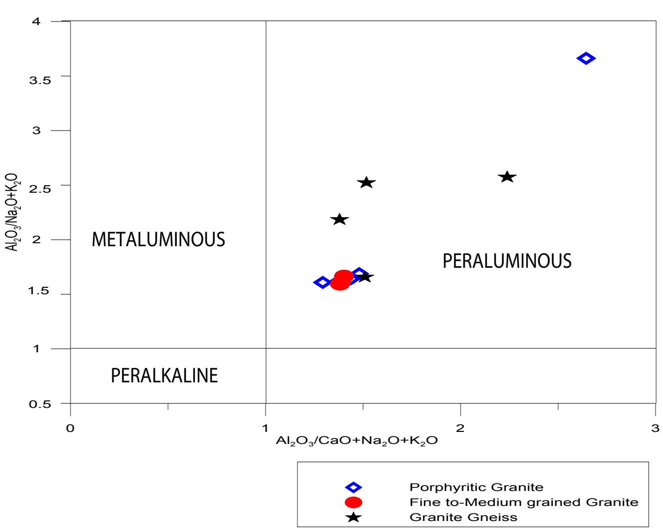

Figure 7: $Al_2O_3/(Na_2O+K_2O)$ versus $Al_2O_3/(CaO+Na_2O+K_2O)$ molecular plot for the granitic rocks of Idofin-Osi-Eruku area (after Maniar and Piccoli [14].

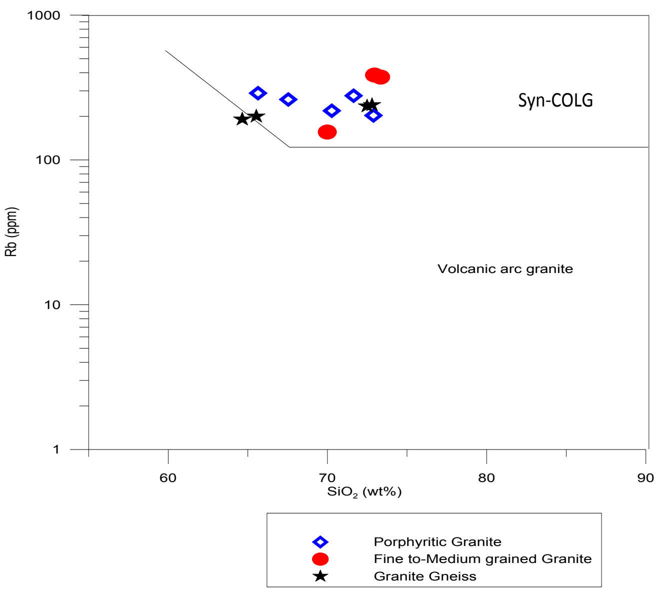

Figure 8: Rb versus SiO_2 plots for the granitic rocks of Idofin-Osi-Eruku area (adopted from Pearce et al [15] Syn-COLG= Syn-collisional granit.

can also plot in the volcanic arc and syncollisional fields [15]. This agrees with findings of Fitches et al on the Older Granites of Nigeria, which origin is consistent with an arc or syncollisional regime.

The result of the geochemical analyses of granitic rocks in the area indicates higher silica composition of 64.65 to 73.34wt%, which is consistent with S-type granitoids, they are largely peraluminous, relatively potassic and their geotectonic settings indicate volcanic arc and Syn-collisional granites. Granitoids recognized from Lachlan fold belt of eastern Australia are S-type granitoids, they are strongly peraluminous, relatively potassic with higher silica compositions (64-77 wt% SiO_2), and S-type granitoids composition ranges from magnesian to ferroan and calcic to alkalic [16]. While similar granitic compositions (S-type granitoids) can be produced by partial melting of a variety of sources [17] and these S-type granites are syn-collisional granitoids [15], continental collision granitoids [14] and muscovite-per aluminous granites [18].

The geochemical data indicates that the varying ratios of incompatible elements with values of Rb/Sr ratio (0.664 to 1.388) in the porphyritic granite, (0.338 to 2.390) in the fine to medium-grained granite, and (0.593 to 1.509) in granite gneiss are higher than the value of Rb/Sr ratio (0.029) in the early gneiss. The values of Ba/Sr ratio (2.815 to 5.424) in porphyritic granite, (3.463 to 4.636) in fine to medium-grained granite and (2.132 to 4.734) in granite gneiss are higher than the value of Ba/Sr ratio (0.912) in the early gneiss. The values of Ba/Rb ratio (2.486 to 6.192) in porphyritic granite, (1.473 to 1.520) in the fine to medium-grained granite and (3.183 to 3.595) in the granite gneiss are lower than the value of Ba/Rb ratio (31.02) in the early gneiss. The geochemical data show large variation in the ratios of the incompatible elements with higher values of the ratios of Rb/Sr and Ba/Sr, and lower values of ratio of Ba/Rb in the granitic rocks than the lower values of the ratios of Rb/Sr and Ba/Sr, and higher value of ratio of Ba/Rb in the early gneiss. This indicates high fractionation which can be attained by magmatic differentiation. The lower ratios of Ba/Rb in the granitic rocks than in the early gneiss further suggest fractionation trends [8,19,20]

The limited variation in the ratios of the incompatible elements of Rb/Sr, Ba/Sr and Ba/Rb for each group of the granites support partial melting and each granitic rock suite was affected by variable degree of partial melting. Based on field evidences, the granite gneiss is the oldest granitic rock in Idofin-Osi-Eruku area because it occurs as xenoliths within the porphyritic granite in Erinmope-Ekiti while fine to medium-grained granites occur as intrusive in the porphyritic granite and is therefore the youngest granitic rock.

Rare earth elements geochemistry

The porphyritic granite and fine to medium-grained granite exhibit similar Rare-Earth Elements (REE) distribution patterns with granite gneiss. The granitic rocks show high degree of fractionation with steep patterns, especially the Light Rare-Earth Elements (LREE) (La to Sm) fractionation relative to Heavy Rare-Earth Elements (HREE) (Gd to Lu) which exhibit varying degree of depletion in the area. Figures

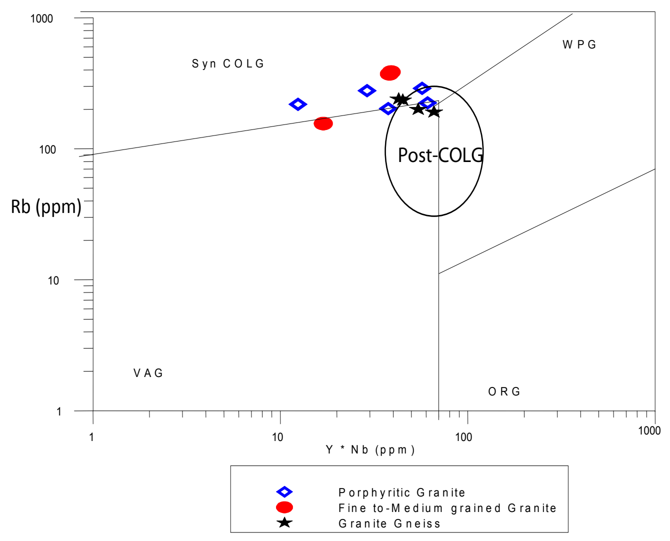

Figure 9: Rb versus Y + Nb discrimination plot for the granitic rocks of Idofin-Osi-Eruku area (after Pearce et al, [15] Syn-COLG= Syn-collisional granite; Post-COLG=Post collisional granite; VAG=volcanic arc granite; WPG=within plate granite; ORG=Ocean ridge granite.

10-12 shows the chondrite-normalized Rare-Earth Elements (REE) distribution patterns of the granitic rocks of the area. The similarities in the Light Rare-Earth Elements (REE) patterns of the porphyritic granite and fine to medium-grained granite with the granite gneiss suggest similar origin.

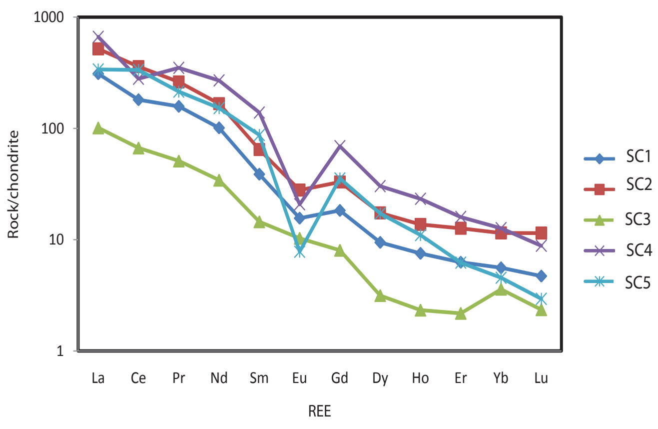

Figure 10: Chondrite-normalized REE distribution patterns of the porphyritic granite of the area.

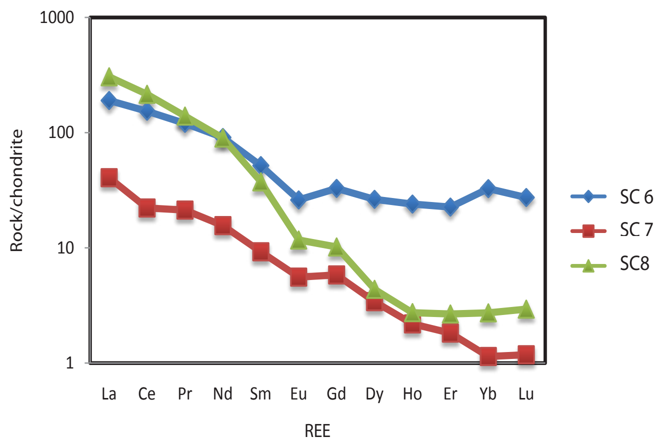

Figure 11: Chondrite-normalized REE distribution patterns of the fine to medium-grained granite.

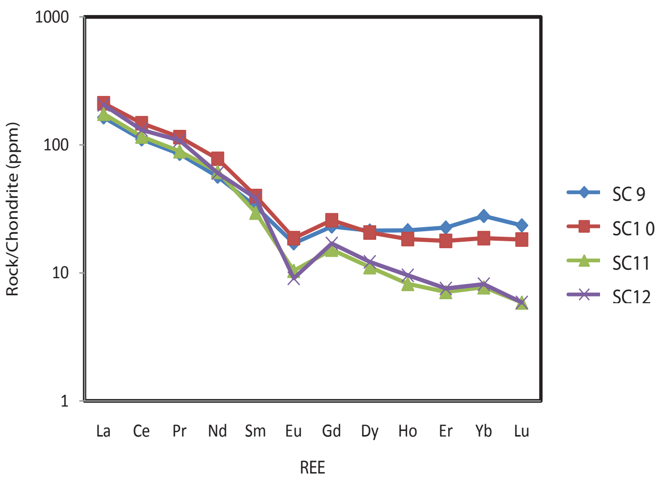

Figure 12: Chondrite-normalized REE distribution patterns of the granite gneiss from Idofin-Osi-Eruku area.

The porphyritic granite are much more enriched with ΣREE values of 362.33ppm, 656.18ppm, 127.73ppm, 742.91ppm and 561.65ppm. The fine to-medium grained granite has- enriched ΣREE values of 315.28ppm, 51.19ppm and 374.94ppm while the granite gneiss has ΣREE values of 232.24ppm, 295.82ppm, 227.41ppm and 254.53ppm respectively. All the granitic rocks have enrichment in the Light Rare-Earth Elements (LREE) relative to the Heavy Rare-Earth Elements (HREE). The enrichment factors ranges between 16.65 to 25.49 in porphyritic granite, 7.38 to 51.81 in fine to-medium grained granite and 6.60 to 16.08 in the granite gneiss. The high level of enrichment in the Light Rare-Earth Elements (LREE) relative to the Heavy Rare-Earth Elements (HREE) in all the granitic rocks suggests high degree of fractionation. Light Rare-Earth Elements (LREE) enrichment relative to the Heavy Rare-Earth Elements (HREE) has been recorded in the granitic rocks from other parts of the Precambrian Basement Complex of Nigeria [19,21]. The abundances and distribution patterns of the Rare-Earth Elements (REE) of the granitic rocks of the study area compare very closely with the fine-grained granite and granite gneiss of Ado-Ekiti-Akure region, southwestern Nigeria [22] which is typical of the crust and also of calc-alkaline rocks.

The normalized ratios of La_N/Yb_N range from 28.19 to 74.42 in porphyritic granite, 5.82 to 111.91 in fine to-medium grained granite and 5.89 to 25.12 in the granite gneiss. The normalized ratio of Ce_N/Yb_N range from 18.6 to 73.63 in porphyritic granite, 4.70 to 78.94 in fine to medium-grained granite and 3.97 to 16.00 in granite gneiss. The normalized ratio La_N/Sm_N ranges from 3.88 to 8.03 in porphyritic granite, 3.67 to 8.17 in fine to medium-grained granite and 4.96 to 5.92 in granite gneiss. The high values of the normalized ratios of La to Yb, Ce to Yb and La to Sm are evidence of high degree of fractionation, which show that the Rare-Earth Elements (REE) patterns are Light Rare-Earth Elements (LREE) enriched with the higher values recorded in the more fractionated porphyritic granite and fine to medium-grained granite than the granite gneiss. The negative Eu anomalies in the granitic rocks (Figures 10-12) show that high amount of plagioclase was removed from the felsic magma during fractional crystallization [23].

Conclusion

Geochemical characteristics show that the granitic rocks of Idofin-Osi-Eruku area are potassic, Fe-enriched and largely peraluminous. The granitic rocks are products of volcanic arc magmatism probably associated with the late stages of the Pan-African Orogenic event. The composition of the granitic rocks in the area is consistent with S-type granite, because they are strongly peraluminous, relatively potassic, have higher silica content of 64.65 to 73.34% and plot as syncollisional and volcanic arc granites.

Higher ratios of Rb/Sr (0.34-2.39) and Ba/Sr (2.44-5.42) in the granitic rocks than Rb/Sr (0.029) and Ba/Sr (0.91) in the early gneiss. And lower ratio of Ba/Rb (1.47-6.19) in the granitic rocks than Ba/Rb (31.02) in the early gneiss indicate high fractionation associated with magmatic differentiation. The granitic rocks have fractionated Rare-Earth Elements (REE) patterns characterized by Light Rare-Earth Elements (LREE) enrichment, which is typical of the crust and also of calc-alkaline rocks. The rocks also show negative europium anomalies and varying degrees of Heavy Rare-Earth Elements (HREE) depletion. The high values of the normalized ratios of La_N/Yb_N, Ce_N/Yb_N and La_N/Sm_N are evidence of high degree of fractionation, and this indicate that the Rare-Earth Elements (REE) patterns are Light Rare-Earth Elements (LREE) enriched with the more fractionated porphyritic granite and fine to medium-grained granite than the granite gneiss. The similarities in the Rare-Earth Elements (REE) patterns of the porphyritic granite and fine to medium-grained granite with the granite gneiss suggest similar origin.

The granite gneiss, porphyritic granite and fine-to medium-grained granite plots in the volcanic arc and syn-collisional granite fields. This agrees with findings of Fitches et al. on the Older Granites of Nigeria, which origin is consistent with an arc or syncollisional regime. Based on the overall abundances of Rare-Earth Elements (REE) and limited variation in the incompatible elements ratios of Rb/Sr, Ba/Rb and Ba/Sr for each group of the granites support partial melting. The process of derivation of the granitic rocks of Idofin-Osi-Eruku area was by volcanic arc magmatism and each granitic rock suite was affected by variable degree of partial melting.

References

1. Annor AE (1995) U-Pb Zircon age for Kabba-Okene granodiorite gneiss: Implication for Nigeria's Basement Chronology. Africa Rev 2: 101-105.
2. Dada SS, Briqueu I, Birck JL (1998) Primordial crustal growth in northern Nigeria: Preliminary Rb-Sr and Sm-Nd contains from Kaduna migmatitic-gneiss Complex. Journal Mining Geology 34: 1-6.
3. Rahaman MA (1988) Precambrian Geology of Nigeria. Geology Survey of Nigeria 11-41.
4. Emmermann R, Daieva L, Schneider J (1975) Petrologic significance of rare earths distribution in granites. Contributions to mineralogy and petrology 52: 267-283.
5. Obiora SC, Ukaegbu VU (2010) Preliminary investigation of the petrogenesis and geotectonic setting of the Precambrian Basement Complex rocks around northcentral Nigeria using trace and rare-earth elements geochemistry. Journal Mining Geology 46: 127-137.
6. King BC, de Swardt AMJ (1949) The Geology of the Osi area, Ilorin Province. Geological Survey of Nigeria Bulletin.
7. Ruth EW (2005) USGS/Central Region/Crustal Imaging & Characterization Team. US Geological Survey, USA.
8. Taylor S (1965) The application of trace element data to problems in petrology. Physics and Chemistry of the Earth 6: 133-213.
9. Levinson AA (1974) Introduction to Exploration Geochemistry. Applied Publishing Ltd, Wilmette, Illinois, USA.
10. Maitre LRW (1976) TThe Chemical Variability of some Common Igneous Rocks. J Petrology 17: 589-598.
11. Rickwood PC (1989) Boundary lines within petrologic diagrams which use oxides of major and minor elements. Lithos 22: 247-263.
12. Frost BR, Barnes CG, Collins WJ, Arculus RJ, Ellis DJ, et al. (2001) A Geochemical classification for granitic rocks. J Petrology 42: 2033-2048.
13. Frost CD, Frost BR (1997) High-K, iron-enriched rapakivi-type granites: the tholeiite connection. Geology 25: 647-650.
14. Maniar PD, Piccoli PM (1989) Tectonic discrimination of granitoids. Geological Society America Bulletin 101: 635-643.
15. Pearce JA, Harris NBW, Tindle AG (1984) Trace Element Discrimination Diagrams for the Tectonic Interpretation of Granitic Rocks. J Petrology 25: 956-983.
16. Chappell BW, White AJR (1974) Two contrasting granite types. Pacific Geology 8: 173-174.
17. Miller CF (1985) Are strongly peraluminous magmas derived from pelitic sedimentary sources. J Geol 93: 673-689.
18. Barbarin B (1990) Granitoids: main petrogenetic classification in relation to origin and tectonic setting. J Geol 25: 227-238.
19. Obiora SC, Ukaegbu VU (2010) Preliminary investigation of the petrogenesis and geotectonic setting of the Precambrian Basement Complex rocks around northcentral Nigeria using trace and rare-earth elements geochemistry. Journal Mining Geology 46: 127-137.
20. Rajesh HM (2007) The petrogenetic characterization of intermediate and silicic charnockite in high grade terrains: a case study from southern India. Contrib Mineral Petrol 154: 591-606.
21. Onyeagocha AC (1986) Geochemistry of basement granitic rocks from northcentral Nigeria. J Afr Earth Sci 5:651-657.
22. Olarewaju VO (1988) REE in the charnockitic and associated granitic rocks of Ado-Ekiti-Akure, S.W. Nigeria. In Precambrian Geology of Nigeria, Geological Survey of Nigeria, Kaduna south, Nigeria.
23. Rollinson HR (1993) Using geochemical data: Evaluation, Presentation and Interpretation. Longman, UK.
24. Boher M, Abochami W, Michard A, Albarede F, Arndt NT (1992) Crustal growth in West Africa at 2.1Ga. Journal Geophys Res 97: 345-369.