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PETROLOGY OF INTRUSIVE ROCKS OF OBAN MASSIF, SOUTHEASTERN NIGERIA

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ABSTRACT

A total of forty- nine (49) fresh rock samples of the various intrusive rocks (granitoids and dolerites)were collected from the field. These rocks intruded metamorphic rocks that include pyllites, schists, gneisses and amphibolites in the Oban Massif. Intrusive rocks pegmatitic granites and granodiorite exhibit porphyritic texture rich in feldspars, quartz, muscovite, biotite, tourmaline and beryl. The granodiorite contains xenoliths of metamorphic rocks. The dolerites are ophitic and composed of plagioclase, olivine and pyroxene. From the geochemical analyses, the intrusive rocks show SiO_2 to be the most abundant chemical component in all the rock units with its highest value recorded in the pegmatitic granite (Av. 70.07%), while the lowest value (59.68%) recorded in the dolerite. Al_2O_3 also display high concentration in rocks of Oban Massif. The rocks have concentrations of Al_2O_3> (CaO + Na_2O + K_2O), low MgO, and TiO_2 concentrations while pegmatitic granites exhibit low concentration in FeO_{Total}. The alkaline and calc-alkaline, granitoid intrusives in the study area were found to be I-type crustal orogenic granitoids that represent a late stage intrusion along major shear and thrust zones.The results of trace elements analysis revealed that almost all the intrusive rocks of Oban Massif contain high Ba content, the highest values occur in the pegmatitic granite with a mean concentration of (2266ppm), while meladiorite was found to contain the least amount of Ba (44ppm).

KEYWORDS: Petrographic, Ophitic, Porphyritic Texture, Calc-alkaline, I-type.

INTRODUCTION

The Precambrian Basement Complex of Nigeria is that part of the African crystalline shield, lying within the Pan-African mobile belt that is sandwiched between the West African Craton to the west and the Congo craton to the east (Fig. 1).The Nigerian Basement Complex is believed to have undergone polyphase deformation during the Precambrian (Onyeagocha, 1984; Ekwueme and Onyeagocha, 1985; Edem et al., 2015; Oden et al., 2017; Ekwueme and Okoro, 2019) the polyphase deformation resulted in complex structures associated with the Nigerian basement.

The area investigated is a part of Basement Complex of Nigeria. Igneous rocks of Oban Massif intruded schists, gneisses and amphibolites. The intrusive rocks in the area have been reported to be late Pan-African in age (Oden and Igonor 2012a). The area of study is located between latitudes 5°05'N to 5°45'N and longitudes 8°05'E to 8°55'E and is within Cross River State. It lies within the equatorial rainforest zone and is relatively densely forested which makes field study of rocks in some parts of the area somewhat difficult. The objective of this report is to provide petrographic descriptions, major and trace elements geochemistry of the intrusive rocks in Oban Massif.

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GEOLOGY OF THE STUDY AREA

About two thirds of the Oban Massif is underlain by crystalline rocks. The Oban Massif Basement is unconformably overlain to the south by the Calabar Flank, which consists of Cretaceous –Tertiary sediments. It is also thought that the Oban Massif and the Obudu Plateau were continuous Precambrian Basement features before the depression and deposition of sediments in the Ikom-Mamfe embayment during the Cretaceous (Petters et al., 1987). The Oban Massif in certain places attains a height of about 1200m above mean sea level (Ekwueme and Okoro, 2019). The western flank is fairly undulating with an elevation of about 30-150m above mean sea level (Essoka and Oku, 2015).The area has undergone polyphase deformation. The deformation events that affected the Oban Massif are results of Eburnean and Pan-African event (Ekwueme, 1985). The most recent event was the Pan-African tectonothermal event. Each of these events has left structural imprints on the basement rocks of the complex as suggested by several workers on the Nigerian basement including Rahaman et al., 1981; Onyeagocha and Ekwueme, 1982; Ephraim, 2009; Igonor, et al., 2011; Ukwang et al., 2012; Oden 2012; Opara et al.,; 2014; Obi et al., (2014) Edem et al., 2015; Asinya et al., 2016; Edem et al., 2016; Ekwueme and Okoro, 2019. It is however, thought that the Pan-African deformation event was widespread and very pervasive to the extent that it probably, totally obliterated all preceding structural imprints of earlier orogenies. Consequently, the geometric characteristic of structures in the Oban Massif is expected to reflect mainly the Pan-African event of 600 ± 150 Ma. The gneisses, which in some places have been migmatized and folded, predominate in the area and appear to be much more prevalent eastward, whereas the schists are exposed on the western part of the basement. The area includes such mappable metamorphic rocks units as phyllites, schists, gneisses and amphibolites. The intrusive rocks in the area are: pegmatite, granite, granodiorite, diorite, charnockite, syenite, tonalite, dolerite and monzonite (Fig. 2).

Oden et al., (2010) studied rocks of the area and they reported that the granite and granodiorite from Oban Massif belong to the syntectonic older granite in the basement of southeastern Nigeria, and were formed during the Pan African orogeny.

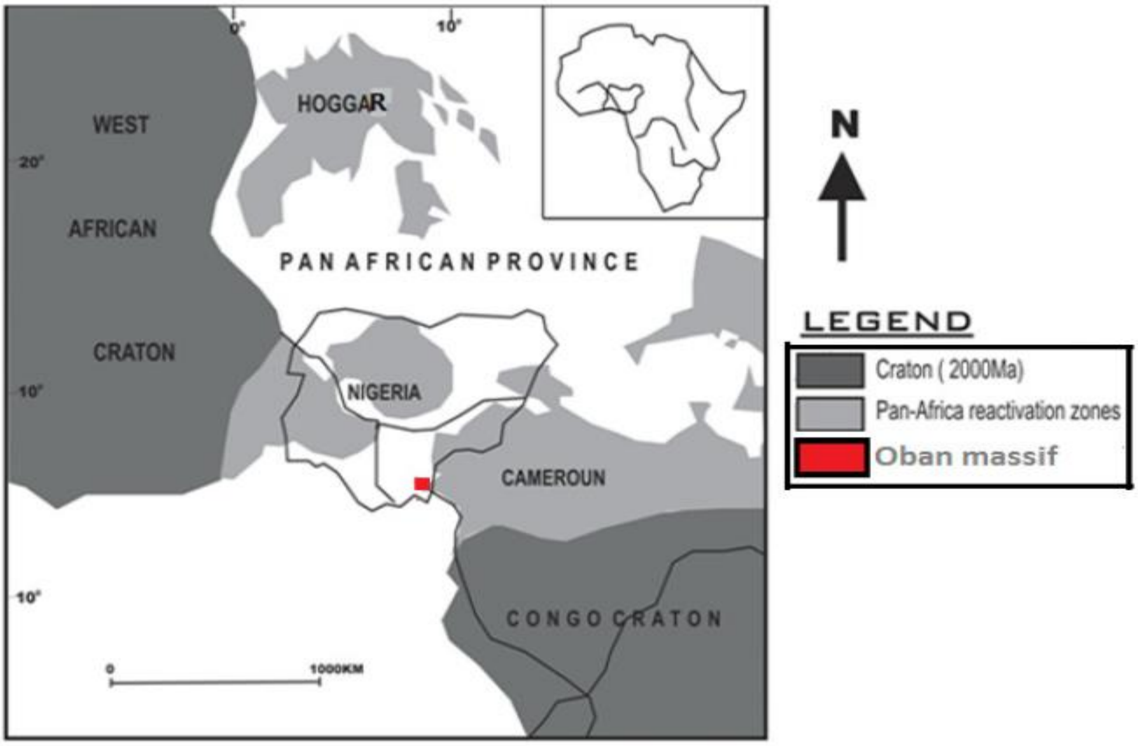


FIG. 1: Map showing the Basement Complex as part of the Pan-African province (Adapted after Elueze, 1985)

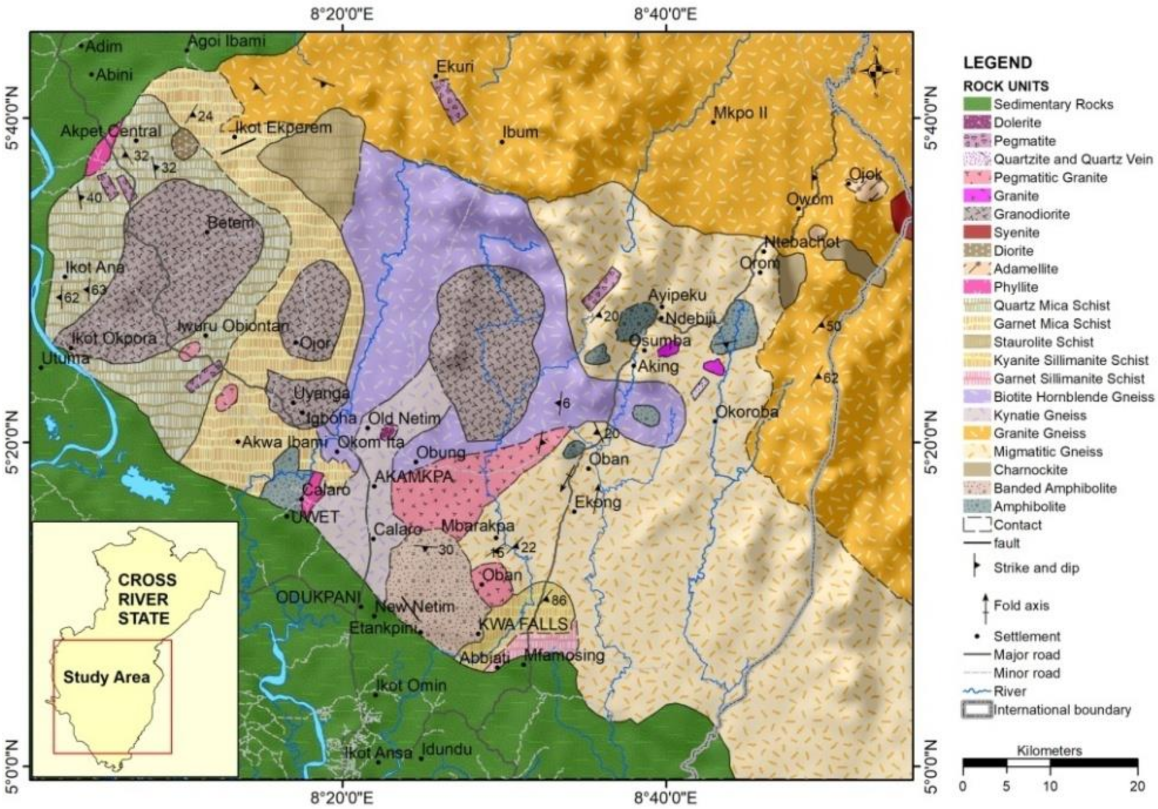


FIG. 2a: Geological map of Oban Massif, southeastern Nigeria (Modified after Ekwueme, 1985)

METHODOLOGY

A total of forty-nine (49) fresh representative rock samples, which were lithologically described based on their texture and field relationships, were collected. Strikes and dips of outcrops and structures were taken using compass clinometers. Adequate attention was given to the nature of the topography and vegetation. Petrographic study started from the field where the samples were described megascopically using hand lens. The samples were then proceeded to the laboratories for petrological analysis. Forty-nine (49) thin sections of the representative samples were prepared for petrological analysis at the laboratory of the Department of Geology, University of Calabar, while ten (10) representative fresh rock samples were pulverized for major and trace elements geochemical analyses, using the Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) technique at the Acme Laboratories Vancouver, Canada.

RESULTS

FIELD DESCRIPTION OF INTRUSIVE ROCKS OF OBAN MASSIF

Granodiorite

Granodiorite occur as intrusive bodies, into the basement in the study area. These rocks crop out at Betem, Ikot Okpora, Ojo, Uyanga, Igbofia, Kwa River, Old Netim and Uwet (Fig. 2a). The granodiorites are dark grey in colour, and variable in texture (medium to coarse-grained). It is the most extensive intrusive rock in the study area. Megascopically, large K-feldspar crystals (phenocrysts) having dimensions of over 0.5cm x 3.5cm are abundant in the rock (Fig. 3).The intrusive granodiorite which generally trend NW – SE show a fabric defined by a well-developed N – S to NNE – SSW preferred orientation of the feldspar megacrysts. Field relationships of intrusive rocks in Oban Massif, suggest that they were not formed by high-grade regional metamorphism, but were intruded into the metamorphic rocks. Quartz, biotite, and muscovite are also realized in hand specimen. Schists and gneisses are seen as xenoliths in the granodiorite of Oban Massif.

Charnockite

In the Oban Massif, charnockite form part of the Precambrian Basement rocks and are non-foliated to weakly foliated. These rocks are medium to coarse-grained and are greenish in fresh exposures but brownish where spheroidally weathered. Charnockite rocks were seen as scattered discrete boulders in the field (Fig. 4). Minerals recognized in hand specimen are large crystals of feldspars, quartz and clinopyroxene. The outcrops of charnockite in the study area have a northeasterly trend and are best exposed at Nyaje, Orem, Ikpai, Ntebachott and Owom (Fig. 2).The host rocks of charnockite in the study area are dominantly migmatitic gneisses.

Dolerite

Dolerite is a dark grey to black intrusive igneous rock. They occur mostly as dykes cutting Precambrian gneisses and schists which are the dominant metamorphic rocks in the area. All dolerites in the study area have similar texture and mineralogy, being fine to medium-grained, and non-foliated (Fig. 5). Dolerites exhibit ophitic to sub-ophitic texture. They consist of phenocrysts of olivine, orthopyroxene as well as laths of plagioclase. Some of the dolerite dykes are riddled with numerous white specks of zeolite (Fig. 5a). The dolerites are unmetamorphosed and show no effects of deformation. The dolerites in the eastern Oban Massif are fine-grained in texture. The contact of the dolerite dykes with the country rocks is sharp, like the one that occurs at Ehom. This reflects the shallow level of their emplacement which would favour rapid cooling of the parent magma. The outcrops show a general trend in NE-SW direction suggesting that their emplacement must have been structurally controlled. The NE-SW trend is sub-parallel to the regional trend of the country rocks.

Meladiorite

Outcrop of meladiorite is found around Igbofia and Uyanga (Fig. 2a & b). It is dark in colour and medium-grained. It occurs as a xenolith in the granodiorite exposed at the Igbofia Rubber Plantation and is thought to be the oldest pluton in the Uwet area and also regarded as older granite intrusion in Nigeria (Ekwueme, 1985). The meladiorite rock is sometime seen as xenoliths in granodiorite.

Pegmatitic Granites

In the Oban Massif, pegmatitic granites are associated with low, medium and high grade metamorphic rocks. Pegmatitic granites are coarse-grained and non-foliated (Fig. 6) and most intrusions of pegmatitic granite bodies have undergone considerable weathering and have formed secondary (placer) deposits. The rocks have a simple mineralogy consisting of largely quartz and feldspars. However, variations occur in pegmatite where minerals like tourmaline, muscovite and beryl are present. These rocks are leucocratic and have interlocking crystals relationship of the constituent minerals in random orientation. Most of the granites in Oban Massif area are pegmatitic. They are probably formed from residual of magmatic fluids. Crystallization from these fluids occurred at very low temperature and at slower rate making it possible for large crystals to form.

PETROGRAPHY OF INTRUSIVE ROCKS OF OBAN MASSIF

Petrographic examination of the intrusive rocks in thin section revealed that the major constituent minerals of the granitic and doleritic intrusive rocks in the study area are quartz, feldspar, biotite, muscovite, pyroxene and olivine minerals. The mineral compositions of these rocks are presented in Table 1.

In thin section, the granodiorite compositions are mainly quartz, plagioclase, biotite, muscovite, hornblende, K-feldspar and opaque minerals (Figs. 7and 8) show inter-relationship of the various minerals occurring in the granodiorite of Oban Massif. Muscovite is colourless to pale green in plane polarised light but pinkish in cross polarised light; it has one direction of cleavage and extinction angle of $3^{0.}$ Quartz is colourless in thin section. Hornblende grains show high relief and are the most common mafic mineral followed by biotite in the rocks of Oban Massif. In some thin section samples, the hornblende is intergrown or has contact with biotite. Generally, the plagioclase feldspar in the rocks of Oban Massif appears colourless with multiple twinnings under plane polarised light (PPL), and has composition of bytownite to labradorite ($Ab_{27.41-}$ $A_{b33.42}$). The crystals are subhedral; this may be due to little or no alteration. Intergrowth of plagioclase feldspar and quartz occurs as worm-like structure called myrmekite (Fig. 7b) in granodiorite of Oban Massif.

Charnockite thin section studies reveal equigranular texture. The minerals identified under petrological microscope are quartz, hornblende, plagioclase and biotite. The average modal compositions of the charnockite are shown in Table 1 and Fig. 9. All dolerites in the area have similar texture and mineralogy, being fine to medium-grained. They consist of phenocrysts of olivine, dominant orthopyroxene as well as laths of plagioclase (labradorite).The petrography of dolerite of Oban Massif reveals (57%) of plagioclase feldspars as the essential mineral and orthopyroxene (31%) and olivine (11%) contribute to the remaining parts of the modal rock composition (Fig. 10). The meladiorite rock contains quartz, biotite, plagioclase (An_{27}) and hornblende, and often with accessory minerals (Fig. 11). The composition of plagioclase in the meladiorite of Oban Massif reveals oligoclase.

In thin section, the pegmatitic granites consist mainly of quartz, K-feldspar, plagioclase, muscovite, hornblende, biotite, and opaque minerals, (Fig. 12). Some sample of pegmatite is enriched in microcline, beryl, galena and tourmaline. Microcline shows polysynthetic twinning (cross-hatched twinning) with extinction angle of $15^{o}$and in some samples it shows dusty alteration to sericite. It is colourless under plane polarised light. Biotite is brownish in colour, with subhedral to anhedral crystal form, no twinning, and has one direction of cleavage. Most of the biotite in thin section show parallel extinction angles of 3^{o} or more. The cleavage shows perfect to imperfect one directional cleavage. In some samples, the biotites are characterized by parallel to sub-parallel arrangement of tiny flakes of biotite. The composition of K-Feldspar in pegmatitc granites is Or_{23-64}.

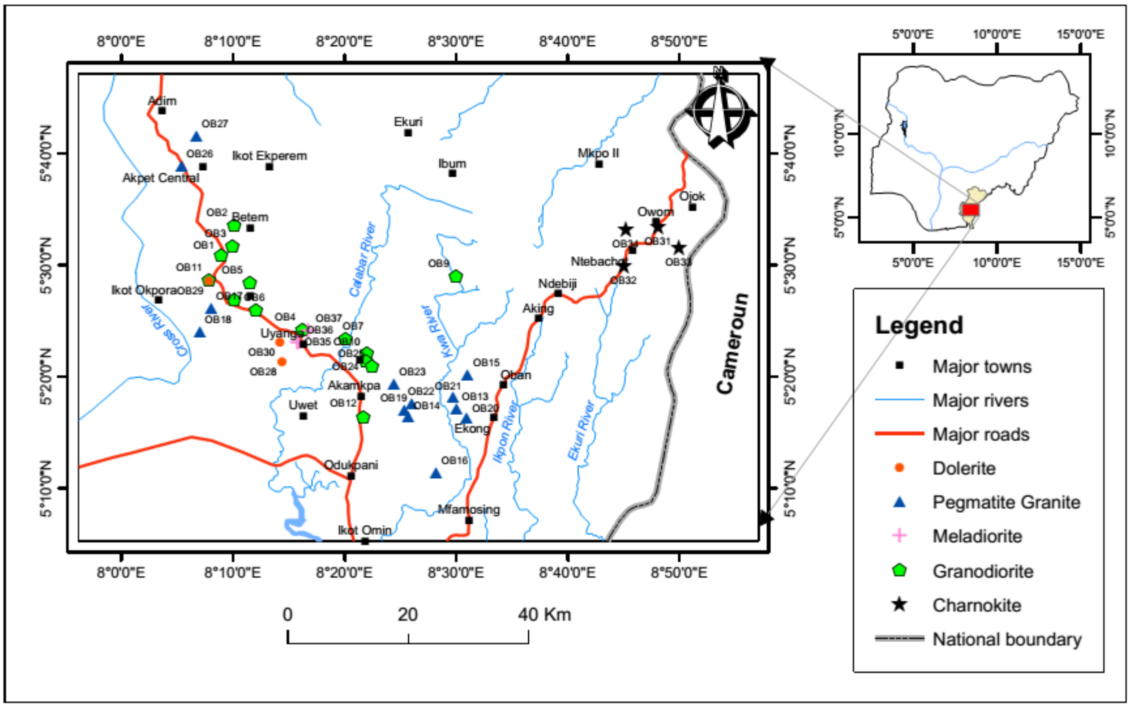


FIG. 2b: Samples Location Map of Oban Massif Southeastern Nigeria

Fig. 3 (a). Granodiorite in Uyanga containing xenoliths of meladiorite. (b) Exfoliation, weathering of granodiorite in Igbofia of Oban Massif.

Fig.4: Field occurrence of the charnockite as seen in Owom village. The rounded bodies of rock materials are products of the physical weathering and erosion of the rock mass.

Fig. 5(a) close-shot photograph of the dolerite reveals a numerous white specks of zeolite on its surface. (b) Field occurrence of a dolerite dyke in Ehom village

Fig. 6: Field occurrence of pegmatite withberyl in the study area

TABLE: 1 Average modal composition of intrusive rocks in Oban Massif, Southeastern Nigeria

Minerals	Gd	Chk	Do	Md	PG
Quartz	17.00	27.00	1.00	12.00	26.00
Biotite	24.30	9.00	-	15.00	12.00
Muscovite	6.10	2.00	-	-	17.00
K-feldspar	16.00	10.00	-	-	16.00
Plagioclase	25.00	15.00	57.00	21.50	8.00
Hornblende	8.60	20.00		26.50	5.50
Tourmaline	-	-	-	-	4.20
Myrmekite	2.00	-	-	-	-
Opaque mineral	1.00	-	-	-	2.00
Pyroxene	-	17.00	31.00	3.00	-
Olivine	-	-	11.00	5.00	-
Epidote	-	-	-	10.00	-
Sphene	-	-	-	2.00	-
Beryl	-	-	-	-	2.00
Galena					2.00

(1). Average of 12 granodiorite (Gd) samples. (2). Average of 8 charnockite (Chk) samples. (3). Average of 6 dolerite (Do) samples. (4). Average of 8 meladiorite (Md) samples. (5). Average of 15 pegmatitic granite (PG) samples.

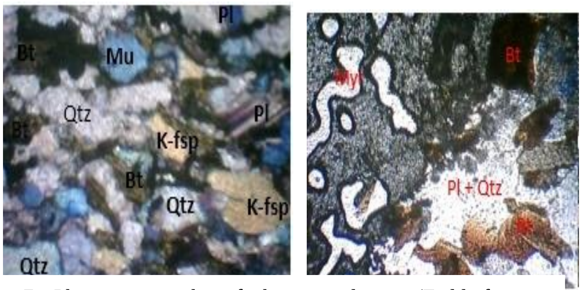


Fig. 7: Photomicrographs of the granodiorite (Field of view X4): (a) showing textural inter relationship of the various minerals occurring in the granodiorite (b) shows myrmekite and reaction between biotite and quartz.

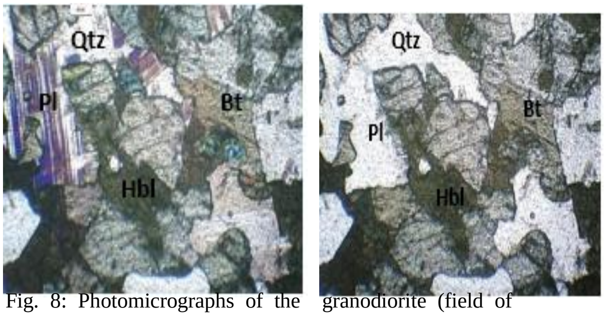


Fig. 8: Photomicrographs of the granodiorite (field of view X4): (a) CPL and (b) PPL showing interlocking of crystals.

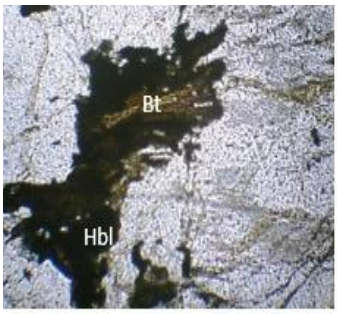


Fig. 9: Photomicrograph of the charnockite (field of view X4): showing hornblende, biotite and quartz.

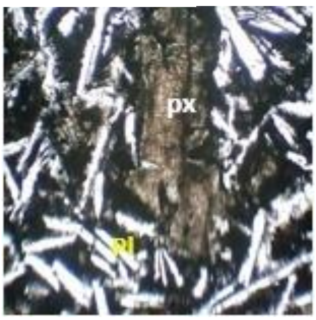
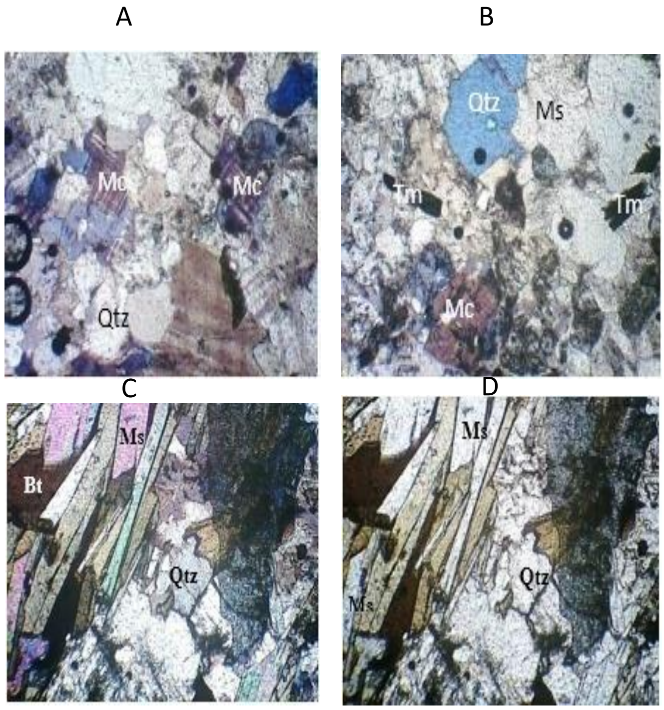


Fig .10: Photomicrograph of the dolerite under PPL (field of view X4): images showing laths in glassy plagioclase groundmass, and pseudomorphs of altered olivine and pyroxene crystals.

Fig: 11 Photomicrograph of meladiorite (Field of view x4**):** showing textural inter-relationships of the various minerals occurring in the meladiorite of Oban Massif area.



Figs. 12: Photomicrographs of the pegmatitic granite (field of view X4): showing the pegmatitic granite to be riched in (a) Microcline (b) Tourmaline (c and d) Muscovite and Biotite (CPL and PPL),

GEOCHEMISTRY

The results of the geochemical analysis and the CIPW norms of the intrusive rocks of Oban Massif are presented in Table 2. The entire intrusive rocks show SiO_2 to be the most abundant chemical component in all the rock units with its highest average value recorded in the pegmatitic granite (PG) (Av. 70.07wt %) while the lowest value 59.68wt% recorded in the dolerite.

Total iron (FeO_{total}) contents is highest in meladiorite 7.24 wt %, and charnockite 7.15wt %, and lowest in the pegmatitic granites (Av. 0.42 wt %). The amount of average potash is highest in the pegmatitc granite (8.61wt %) and lowest in the meladiorite (Md) 0.14 wt%. Average values for soda in pegmatitic granite, granodiorite (Gd), dolerite (Do), meladiorite and charnockite (Chk) were found to be 1.25 wt%, 3.83 wt%, 3.53 wt%, 2.08 wt% and 2.95 wt% respectively. All other oxides MgO, MnO, TiO_2 have values <4wt% in all the samples, exception of meladiorite that is enriched in CaO (14.1 wt%). Meladiorite, dolerite and charnockite are enriched in Fe_2O_3. The LOI between 0.4 and 0.8wt% (less than 1.5 wt%) for the granodiorite which may be an indication that the low temperature overprint does not change the primary magmatic chemical composition significantly (Pudlo, 1993).

Comparatively, the granitoids (pegmatitic granite andgranodiorite) of Oban Massif have mean values of SiO_2that are greater than 68 wt %, this value is in the same range quoted for granitoids rocks from north eastern Somalia (Lenosir et al., 1994) and Paleoproterozoic Zenaga granodiorite of Moroccan metacraton (Ennih and Liegeois, 2008). But these mean values of granitoids of Oban Massif are slightly lower than that obtained from Albala granitic pluton from Spain (Escuder-Esaun et al., 2004) and SW Obudu leucogranitic (Ukwang and Ekwueme, 2009). The SiO_2 value in charnockites of Oban Massif is to some degree similar to charnockite from SW Obudu, Nigeria (Ukwang and Ekwueme, 2009), but quite higher in magmatic chanrockite from Petronella, Zimbabwe (Van Reene and Roering, 1990). Also, SiO_2 value of dolerite in the Oban Massif is higher than the values obtained from Wgwuadu dolerites from Ishiagu, 80km SE of Enugu, Southeastern Nigeria (Ezepue, 1979) and dolerites from north Obudu, Bamenda Massif (Ephraim, 2005).The enrichment in silica content could be due to the assimilation of materials around the rock in which dolerite intruded. It could also be as the result of dolerite in the area that generated from tholeiitic magma sources. Tholiitic is basaltic rocks that are silica saturated, rich in aluminum and low in potassium he concentrations of alkalis (Na_2O + K_2O) in the granitoids rocks from the study area are comparable to those of similar rocks from Obudu , (Ukwang and Ekwueme, 2009), Albala granitic rocks of Span (Escuder-Esaun et al., 2004) and Paleoproterozoic Zenaga granodiorite of the Moroccan metacraton (Ennih and Liegeois, 2008). Al_2O_3 content in granitoids of Oban Massif are comparable to the values for granitoids from north eastern Somalia (Lenoir et al., 1994) and Albala granitic rocks of Spain (Escuder-Esaun et al., 2004). Fe_2O_3 content obtained in Oban Massif basic rocks (meladiorite, dolerite and charnockite) are far higher than what is obtained from Petronella, Zimbabwe (Van Reenen and Roering, 1990) Table 3.

From the CIPW norm of dolerite shows that hypersthenes (7.94 wt%) and olivine (7.16wt%) (Table 2) are seen in the norm of the dolerite, suggesting it to be in the family of olivine tholeiites.

TRACE ELEMENTS

Trace element abundance and elements ratio of intrusive rocks are presented in Table 4. Almost all the rocks of Oban Massif contain high Ba content, but higher values occur in thePG, with a mean concentration of 2266ppm; charnockite, 2146ppm;dolerite, 833ppm; granodiorite 665.8ppm while meladiorite was found to contain the least amount of Ba (44ppm). The mean Ba value of 1783ppm for the granitoids fall within the range quoted by Turekian and Wedepol (1961) for granitic rocks. Zr values are very high in charnockite and dolerite (1070ppm and 783.3ppm)respectively and varies extensively in the other rock types. On the average, Behas a higher amount in pegmatitic granite (3.3ppm) and granodiorite (2.5ppm) than in other intrusive rocks.

DISCUSSION

Oban Massif constitutes a part of the Basement Complex of southeastern Nigeria. The study area is underlain by rocks of the Basement Complex including gneisses, schists, phyllites and intrusive rocks. The intrusive rocks granodiorite, granite and pegmatitic granite exhibit porphyritic texture, whereas dolerites are typical texturally ophitic. Field and petrographic data do not indicate the charnockite have undergone any metamorphism (either regional or contact) at their present level of emplacement.

The granodiorite in the study area contain xenoliths of schists, gneisses, charnockite and meladiorite suggesting that it was emplaced by a stoping mechanism. Oden and Igonor, (2012a,b) and Ekwueme and Okoro, (2019) described granodiorite as being subjected to onion-skin weathering (ex-foliation weathering pattern) and the onion peels are arranged in ellipsoidal patterns around the central core with the longest and shortest axes of the ellipsoids being commonly horizontal (Fig.3) and they appear to align in space.

The dolerite mapped in the Oban area belongs to the olivine tholeiitic class of basaltic rocks, these rocks have widespread occurrence in the basement of southeastern Nigeria, though they are more abundant in Obudu than in the Oban area (Ekwueme, 1990a, b; 1994). The dolerites in the eastern Oban Massif are fine-grained in texture. This reflects the shallow level of their emplacement which favour rapid cooling of the parent magma.

It is suggested that both the Igbofia meladiorite and the Uwet granodiorite seem to have been emplaced by a reactive stoping mechanism (Ekwueme et al., 2013). The reason for their suggestion could be as the result of inclusions that may be recognized as blocks of wall rock that have been mechanically incorporated into the magma body, which is the process called stoping. Meladiorite occurs as a xenolith in the granodiorite exposed at the Igbofia Rubber Plantation. Meladiorite in the study area is dark green to black in colour, contain mostly ferro-hornblende based on the results obtained from the petrographic and geochemical analyses. A plot on Cox et al., (1979) total alkali versus Silica (TAS) (Fig. 14), suggests that the dolerite samples plots in the normal tholeiitic dolerite field, but has silica content (59.68 wt %) higher than the one published by Ekwueme and Onyeagocha (1985) that has average SiO_2 content of 50.00 wt %.The enrichment in silica content could be due to the assimilation of materials around the rock in which dolerite intruded. It could also be as the result of dolerite in the area that generated from tholeiitic magma sources, which are silica saturated, rich in aluminum and low in potassium. The total alkali content of 4.51wt% is high when compared with alkali content of tholeiitic basalts of Hawaii which is 2.60 wt % (Hatch et al., 1972). The values obtained from CIPW norms indicate that Oban Massif dolerites have olivine, hypersthenes and diopside in the norm. The dolerite dyke derived in the area could be obtained from olivine tholeiite magma based on Yoder and Tilley (1962). The occurrence of olivine and hypersthene in the norm of the dolerite places it in the class of olivine tholeiites. According to Green and Ringwood, (1967), Ringwood, (1985) such tholeiitic magma usually segregates from crystal much at a depth of 0-15km in the mantle after 20% or more degree of partial melting of mantle peridotite.

Many pegmatites frequently associated with granitic intrusions suggesting that some of the pegmatites may be related to granitic activities (Onyeagocha, 1984). For the granitoids of the Oban Massif, the dominant lithologic unit is the granodiorite. A zircon evaporation age of 672 ± 2 Ma was obtained by Ekwueme and Kroner (2006) for the granodiorite which intruded the Oban Basement rocks. This age marks the peak Pan-African older granite magmatic activity in southeastern Nigeria and has been interpreted as the emplacement age of the granodiorite.

On the Maniar and Picolli (1989) A/NK versus A/CNK discriminant diagram (Fig. 15), which is based on major elements, the granodiorite plots in the peraluminous field – although the point lies very close to the boundary between metaluminous and peraluminous rocks. According to the chemical classifications of Shand (1943) and Lacroix (1933) the combination of calc-alkali and peraluminous properties implies a crustal origin for the granitoid. However, Barbarin (1990) recognized three types of peraluminous crustal granitoids (C-types) which can be differentiated based on nature of the source, the degree of partial melting, the possible addition of small amounts of mantle-derived component, and the intrusive character. Of these categories, the two-mica intrusive granitoids (C_{ST} type) (Table5) is the best model to explain the petrogenesis of the Oban Massif orogenic granodiorite. The granitoids are generated and emplaced along major shear and thrust zones active during the culmination of collisional events. The shortening and tectonic thickening of the continental crust induce the melting of crustal material and production of monzonitic and granodioritic peraluminous magmas. Locally, addition of small amounts of a mantle-derived component may provide enough energy to make these peraluminous magmas mobile and allow them to intrude into high levels of the crust (Fig. 16) is Total alkali versus SiO_2 plot for rocks of the Oban Massif showing their chemical affinity to known igneous rocks (Le Bas et al., 1986).

A collisional petrotectonic setting for the granodiorites of the Oban Massif is further supported by the trace element-based tectonic discrimination diagrams of Pearce et al., (1984) shown in Fig. 17. Such granitoids are syntectonic (Barbarin, 1990), and Oden (2012) study of dimensional preferred orientation in Uwet Granodiorite of the Oban Massif using phenocrysts of K-feldspar affirms that the granodiorite is a syn-tectonic granitoid. The granodiorite fall in the >30 km crustal thickness field (Fig. 18) on the Rb-Sr crustal thickness index diagram of Condie (1973). Rb, Zr, Sr and Ba/Rb recorded for granitic rocks are normal for granitics derived through partial melting of the crust (Von Platen, 1965) and that Rb/Sr ratios are within the range of values for crustal rocks. The granodiorite of Oban Massif has highest Ba/Rb ratios of 6.72ppm, pegmatites (22.61ppm). According to (Ekwere, 1985), these values are features for fresh rocks. Rhodes, (1975) pointed out that; Ba/Rb ratios have been employed as a useful index of differentiation. The application of Ba/Rb, Rb/Sr and K/Rb ratios assist in obtaining the degree of alteration and fractionation in granitic rocks. The granitic rocks of Oban Massif have Ba/Rb ratios average of (11.81ppm).This values implies that the granitic rocks may have crystallized from a relatively undifferentiated magma. Rb in the granitoids and basic rocks is impoverished compared to the Rb in granite of Banke and Ririwai Younger Granite Complex, northern Nigeria (Ekwere, 1985). Rb has values of 128.5ppm, 199.7ppm, 76.4ppm and 85.8ppm, and 150ppm, 187.3ppm and 86.5ppm for granodiorite and pegmatitic granites respectively, while 76.5ppmfor the dolerite. This depletion of Rb in the granitoid rocks could be as the result of high K minerals in these rocks (Upton, 1960). Ba and Sr values are high in the intrusive rocks of Oban Massif. Noble et al., (1969) observed that the low Ba and Sr values may be due to the protracted fractionation. But this is a reversed in the granitic and basic rocks of Oban Massif. The high Ba and Sr in the granitic rocks of Oban Massif are comparable to those in granitic rocks observed by Taylor, 1965. These could imply that, these elements were easily incorporated into granitic rocks rich in volatile components.

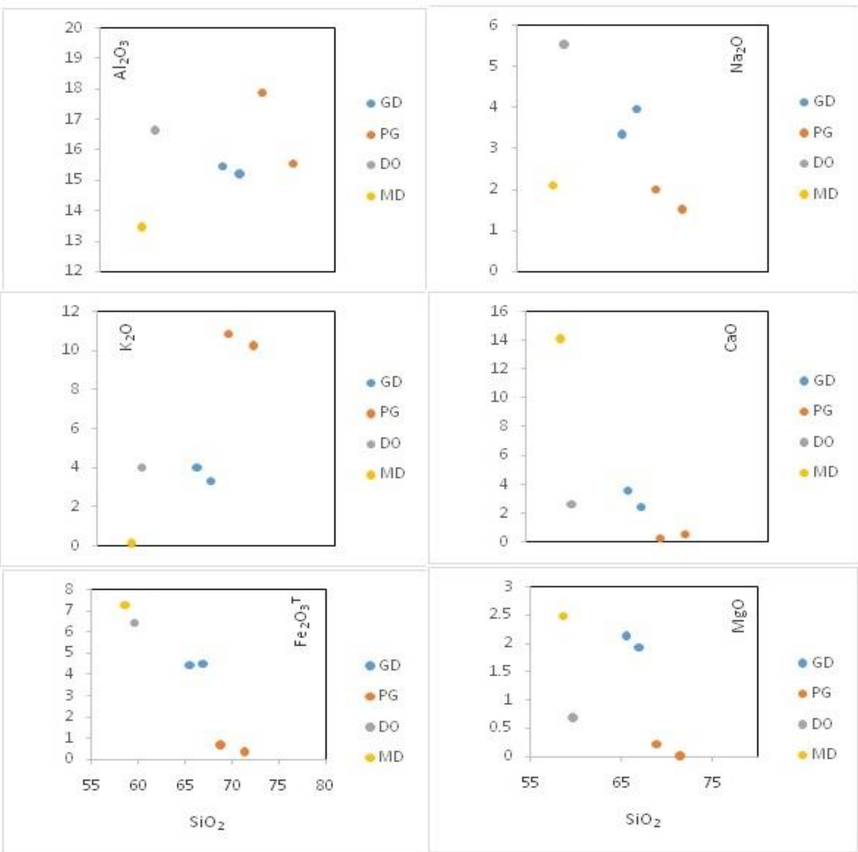


Fig. 13: Silica variation diagrams (Harker diagrams) for TiO_2, FeO, Na_2O, Al_2O_3, MnO, CaO and K_2O for rocks of the Oban Massif showing major elements ranges, patterns and relationships for the intrusive Igneous rocks.

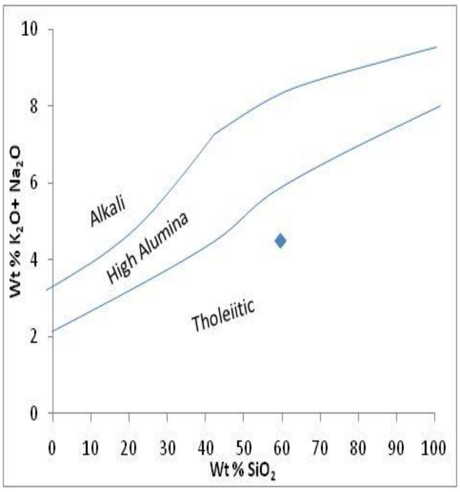


Fig. 14: Total alkali – silica diagram for dolerite igneous rocks of Oban Massif based on the Cox et al., 1979.

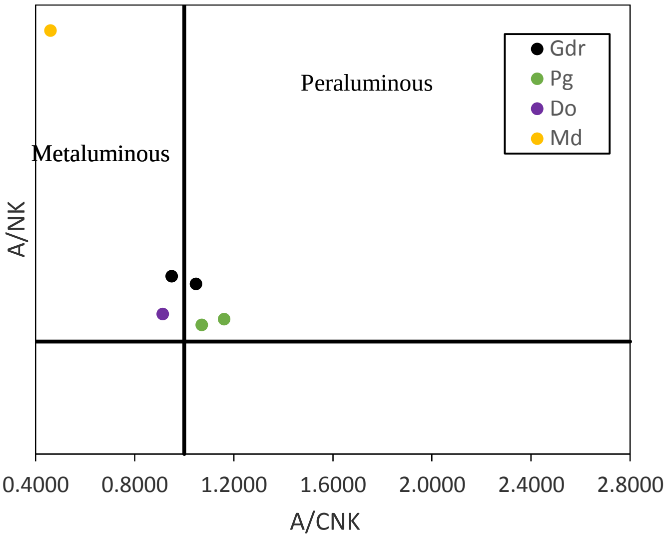


Fig. 15: Alumina-total alkali ratio (A/NK versus A/CNK) plot of rocks of the study area showing the Peraluminous and metaluminous fields. Maniar and Picolli (1989)

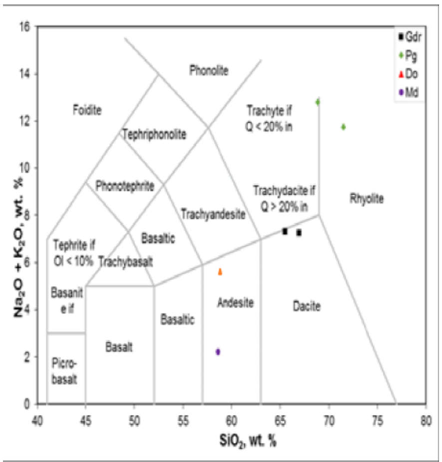


Fig. 16: Total alkali versus SiO_2 plot for rocks of the Oban Massif showing their chemical affinity to known igneous rocks (After: Le Bas *et al*., 1986)

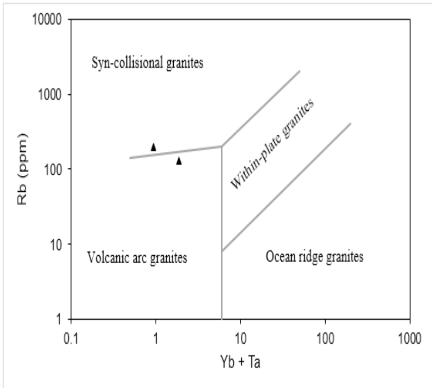


Fig. 17: Tectonic setting discriminant diagram of granodiorite rocks of Oban Massif based on Rb vs Yb + Ta (After: Pearce *et al.*, 1984).

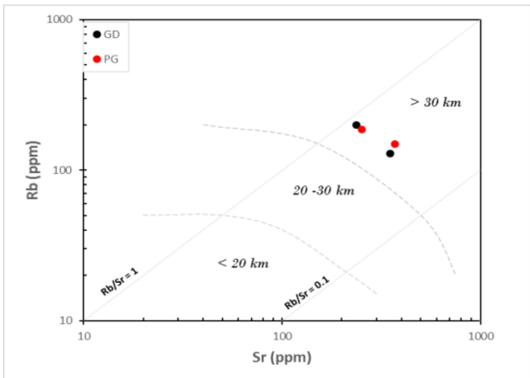


Fig. 18: Rb-Sr crustal thickness index diagram for the granitoids of the Oban Massif (modified after: Condie, 1973).

CONCLUSION

This study has provided a detailed assessment of the mineralogy and geochemistry of the intrusive rocks constituting the Oban Massif Basement of southeastern Nigeria. The Oban Massif Basement Complex of southeastern Nigeria is composed of gneisses, schists and amphibolites. These rocks were intruded by granitic and doleritic rocks. With the exception of the dolerite, the fabric and field disposition of the rocks reflect Pan-African thermotectonic event. The intrusive granodiorite which generally trend NW – SE show a fabric defined by a well-developed N – S to NNE – SSW preferred orientation of the feldspar megacrysts. Field relationships of intrusive rocks in Oban Massif, suggest that they were not formed by high-grade regional metamorphism, but were intruded into the metamorphic rocks. The granitic rocks are derived from a pre-existing crust through partial melting. Xenoliths observed in the granodiorite suggest that magmatic stoping was a major mechanism of emplacement of these rocks. The data obtained from geochemical analyses show that the granitic rocks were intruded as magma. The alkaline and calc-alkaline, granitoid intrusives in the study area were found to be I-type crustal orogenic granitoids that represent a late stage intrusion along major shear and thrust zones. Dolerite in the area was generated from tholeiitic magma sources. The value of Ba/Rb ratios in the rocks of Oban Massif implies that the granitic rocks may have crystallized from a relatively undifferentiated magma. The depletion of Rb in the granitoid rocks could be as the result of high K minerals in these rocks. The high Ba and Sr in the granitic rocks of Oban Massif could imply that, these elements were easily incorporated into granitic rocks rich in volatile components.

When compared, these intrusive rocks show similarities and compositional characteristic similar to other basement rocks in Nigeria as well as basement rocks in some other parts of the world. The granitic rocks show a distinct compositional similarity, perhaps as a result of tectonism and heat flow in the lithosphere, granitic magma was generated.

Table 2: Major element compositions and CIPW norms of igneous rocks of the Oban Massif.

Rock type	GD				PG			DO	MD	CHK
Elements	OB1	OB2	OB3	OB4	OB 5	OB 6	OB7	OB 8	OB 9	OB 10
SiO_2	65.5	66.92	67.9	64.80	68.84	71.46	69.90	59.68	58.59	69.78
Al_2O_3	15.45	15.2	14.43	14.73	17.88	15.53	15.34	16.63	13.46	12.29
Fe_2O_3	4.44	4.48	3.81	4.45	0.62	0.35	0.30	6.4	7.24	7.15
MgO	2.13	1.93	1.10	3.60	0.22	0.01	2.41	3.68	2.48	0.28
CaO	3.56	2.43	2.48	4.14	0.23	0.51	0.35	2.63	14.1	2.18
Na_2O	3.33	3.95	4.24	3.79	1.98	1.5	0.27	3.53	2.08	2.95
K_2O	3.98	3.3	4.2	2.77	10.82	10.25	4.76	0.98	0.14	3.69
TiO_2	0.63	0.51	1.14	0.40	0.05	0.04	0.87	1.65	0.84	0.71
P_2O_5	0.2	0.15	0.15	0.13	0.07	0.02	0.21	0.17	0.15	0.19
MnO	0.07	0.07	0.03	0.07	0.03	<0.01	0.13	0.12	0.16	0.08
Cr_2O_3	0.031	0.054	0.035	0.045	<0.002	<0.002	0.03	0.008	0.041	0.03
Lo1	0.4	0.8	0.5	0.6	1.1	1	2.30	3.2	0.6	0.1
Total	**99.85**	**99.87**	99.96	99.53	**99.73**	**99.67**	99.43	**99.78**	**99.85**	**99.68**
CIPW norm										
Q	18.59	21.27	26.39	16.46	14.91	22.28	19.82	3.31	17.65	30.13
Or	23.52	19.50	24.82	16.37	63.94	60.57	22.81	23.52	0.83	21.80
Ab	28.18	33.42	27.41	32.66	16.75	12.69	28.09	46.79	17.60	24.96
An	15.45	11.07	10.41	14.95	0.68	2.40	15.00	8.80	26.97	9.39
C(A)	0.00	1.07	0.76	0.00	2.66	1.09	0.00	0.00	0.00	0.00
Ap	0.50	0.38	0.73	0.30	0.18	0.05	0.48	0.43	0.37	0.48
Il	1.20	0.97	2.36	0.76	0.09	0.08	1.16	1.23	1.60	1.35
Mt	0.84	0.85	0.74	0.84	0.12	0.07	0.82	1.21	1.37	1.35
Di	0.75	0.00	0.00	3.95	0.00	0.00	0.80	2.72	29.37	0.16
Hy	9.93	10.05	5.94	12.45	1.40	0.42	9.64	7.94	0.00	9.09
Ol	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.16	0.00	0.00
Wo	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.87	0.00

Table 3: Comparison of average of major elements compositions of intrusive rocks from Oban Massif, southeastern Nigeria and similar rocks from regions of the world (wt %)

Elements	1	2	3	4	5	6	7	8	9	10	11	12	13
SiO_2	66.28	70.07	59.68	58.59	69.78	74.20	75.51	67.52	50.60	70.72	74.08	66.46	51.20
Al_2O_3	14.95	16.25	16.63	17.46	12.29	14.29	15.05	15.41	14.87	14.06	9.58	16.45	14.50
Fe_2O_3	4.30	0.42	6.4	7.24	7.15	0.01	1.332	3.46	1.07	0.37	0.79	4.29	12.70
MgO	2.19	0.88	3.68	2.48	0.28	0.02	0.36	1.39	5.06	1.07	2.30	1.42	4.00
CaO	3.15	0.36	2.63	14.1	2.18	0.72	0.59	2.62	8.39	3.16	3.48	1.92	7.40
Na_2O	3.83	1.25	3.53	2.08	2.95	4.00	3.51	4.05	3.12	4.26	4.00	2.78	4.20
K_2O	3.56	8.61	0.98	0.14	3.69	5.55	5.09	3.60	0.80	1.44	1.90	3.84	2.10
TiO_2	0.67	0.32	1.65	0.84	0.71	0.017	0.15	0.48	1.80	0.15	0.92	0.47	2.60
P_2O_5	0.16	0.1	0.17	0.15	0.19	0.04	0.49	0.15	0.32	0.04	0.20	0.18	1.10
MnO	0.06	0.05	0.12	0.16	0.O8	0.01	0.02	-	0.13	0.04	0.01	0.04	0.20
Cr_2O_3	0.04	0.01	0.008	0.041	0.03	-	-	1	-	-	-	-	-
LOI	0 58	1.47	3.2	0.6	0.1	0.32	0.01	1	4.14	0.34	0.46	1.84	-
Total	**99.80**	**99.60**	**99.78**	**99.85**	**99.68**	**99.26**	**100.11**	**100.68**	**99.89**	**99.40**	**99.61**	**98.03**	**100.00**

1. = Major element composition of granodiorites from Oban Massif, southeastern Nigeria (present work)
2. = Major element composition of pegmatitic granites from Oban Massif, southeastern Nigeria (present work)
3. = Major element composition of dolerites from Oban Massif, southeastern Nigeria (present work)
4. = Major element composition of meladiorites from Oban Massif, southeastern Nigeria (present work)
5. = Major element compositions of charnockite from Oban Massif, southeastern Nigeria (present work)
6. = Average major element composition of leucogranite from SW Obudu, Nigeria (Ukwang and Ekwueme, 2009)
7. = Chemical composition of Albala granite pluton, Spain (Escuder-Esaun at al., 2004)
8. = Average major elements composition of granitoids from north eastern Somalia (Lenior et al., 1994)
9. = Average major element composition of dolerite rocks from SW Obudu, Nigeria (Ukwang and Ekwueme, 2009)
10. = Average major element composition of charnockite from SW Obudu, Nigeria (Ukwang and Ekwueme, 2009)
11. = Chemical composition of magmatic charnockite from Petronella, Zimbabwe (Van Reenen and Roering, 1990)
12. = Average major elements composition of Paleoproterozoic Zenaga granodiorite of the Moroccan metacraton (Ennih and Liegeois, 2008)
13. = Average major element composition of Dolerite from North Obudu area, Bamenda Massif (Ephraim, 2005)

TABLE 4: Trace elements compositions (in ppm) of intrusive Igneous rocks in the Oban Massif.

Elements	GD				PG			DO	MD	CHK
	OB1	OB 2	OB3	OB 4	OB5	OB6	OB 7	0B8	OB 9	OB 10
Ba	863	305	710	785	3392	2572	834	833	44	2146
Be	2	5	2	1	2	2	6	3	2	2
Bi	<0.1	0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Co	11.4	9.4	13.4	14.2	8.3	12.4	3.6	2.6	16	5.8
Cs	5.2	13.6	2.3	2.4	1.9	0.9	0.5	0.7	1.6	1.5
Cu	19.8	33.8	10.1	9	7	10.7	6.9	6.97	25.3	18.9
Ga	18.4	26	18.4	17.5	14.8	11.5	30.6	20.6	17.9	22
Hf	4.8	3.5	3.3	3.6	1.5	1.8	18.5	18.5	5.1	26.1
Mo	1.3	1.6	0.4	0.9	0.1	0.3	1.5	1.51	2	3
Nb	9.8	7.5	6.3	4.1	1	1.4	74.1	74.1	12.7	37.6
Ni	21.4	20.1	29.9	30.8	6.9	12.1	1.4	2.4	14.5	5.1
Pb	2.8	3.7	2.5	1.4	8.5	6.9	8.4	6.4	2.4	2.4
Rb	128.5	199.7	76.4	85.8	150	187.3	86.5	76.5	18.2	67.3
Sc	9	7	10	11	1	2	7	6	14	8
Sn	2	4	<1	<1	<1	<1	5	3	2	<1
Sr	350.7	236.9	409.1	407.4	369.4	252.6	198.1	188.2	292.4	286.7
Ta	0.7	0.4	0.7	0.3	0.2	0.1	4.7	3.7	0.9	1.9
Th	10.9	10.5	7.4	6.3	0.7	1.9	10.9	11.9	10.1	13.1
U	3.5	5	1.1	1	0.9	0.8	2.9	2.2	2.2	1
V	83	80	55	69	<8	<8	<8	<8	104	11
W	0.8	1.1	<0.5	<0.5	67.6	33.6	1.3	2.3	3.2	0.9
Y	12.5	5.3	14.6	15.5	1.8	1.8	52.3	52.3	193.1	42.9
Zn	60	110	52	42	90	11	132	132	13	100
Zr	166	118.9	151.1	123.2	53.7	48.5	783.1	783.3	27.1	1070
Sr/Rb	2.729	1.186	5.35	4.748	2.463	1.349	2.29	2.460	16.066	4.26
Rb/Sr	0.366	0.843	0.187	0.211	0.406	0.741	0.437	0.406	0.062	0.235
K/Rb	0.002	0.014	0.046	0.027	0.06	0.045	0.038	0.005	0.007	0.045
Ba/Rb	6.72	1.53	9.29	19.15	22.61	13.73	9.64	10.888	2.42	31.89

Table 5: Relationships between petrogenetic types, magma origin and tectonic settings for granitoids.

- ORIGIN -	- GRANITOID TYPES -		- TECTONIC SETTING -	
CRUSTAL ORIGIN	Intrusive Two-mica Leucogranites	C_{ST}	COLLISION OR POST-COLLISION ZONES	OROGENIC GRANITOIDS
	Peraluminous Autochtonous Granitoids	C_{CA}		
PERALUMINOUS ROCKS	Peraluminous Intrusive Granitoids	C_{CI}		
MIXED ORIGIN (Crust + Mantle)	Potassic Calc-Alkaline granitoids (High K – Low Ca)	H_{LO}		
METALUMINOUS OR CALC-ALKALINE ROCKS	Calc-Alkaline Granitoids (Low K–High Ca)	H_{CA}	SUBDUCTION ZONES	
MANTLE ORIGIN	Island Arc Tholeiitic Granitoids	T_{IA}		
	Midocean Ridge Tholeiitic Granitoids	T_{OR}	RIFTING OR DOMING ZONES	ANOROGENIC GRANITOIDS
THOLEIITIC, ALKALINE OR PERALKALINE ROCKS	Alkaline and Peralkaline Granitoids	A		

(After:Barbarin1990).

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