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THE PETROLOGY OF THE NORTHEASTERN REGION OF OBUDU PLATEAU, BAMENDA MASSIF, SOUTHEASTERN NIGERIA

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ABSTRACTS

Crystalline basement rocks mapped within northeast Obudu area include migmatitic gneisses, migmatitic schists, granite gneisses, metagabbro, dolerites, and amphibolites. The dominant foliation trend in the area is N-S to NE-SW with dips in the northwest. This is an indication that the area was subjected to the Pan-African thermotectonic events (550 ± 100 Ma). The migmatitic gneisses are of quartzo-feldspathic composition and have their metamorphic banding frequently modified by shearing, injections of felsic materials, and by contortions or other complex folding patterns. The migmatitic schist have well-developed schistosity, and occasionally display relict grading, well preserved beddings and syn-sedimentary deformational structures. Both the migmatitic gneisses and schists are frequently associated with quartzitic selvages and ridges which underline the relevance of sedimentary processes in the evolutionary history of these rocks. Field observations and other evidence suggest that the granite gneisses once belonged to a coherent plutonic body that underlies the area. These granite gneisses form the basement for the emplacements of gabbroic rocks and doleritic intrusions, and are extensively dissected by a network of intersecting or crosscutting quartzo-feldspathic stringers or veins/veinlets of various widths and orientations. These indicate the relevance of post-tectonic defomation and deuteric alteration in their evolutionary history. Also present within the granite gneisses are amphibolites which occur as dismembered lenticular enclaves having variable orientations. The dolerites of the area have a lot in common with those of the southern regions, and are therefore most likely genetically related. The structures and mineral paragenetic assemblages present in rocks mapped in the area suggest that apart from the largely unmetamorphosed dolerites, all other rocks in northeast Obudu area have, at least, experienced the highest grade of amphibolite facies metamorphism. Garnet and sillimanite are present as part of the metapelitic assemblages, which point to the fact that the metapelites of northeast Obudu area were metamorphosed to sillimanite facies conditions similar to what obtains in southern Obudu area

KEYWORDS: Northern Obudu, Trans-Saharan Belt, Metapelites,

INTRODUCTION

The Precambrian basement complex of Nigeria lies within the Neo-Proterozoic to Early-Phanerozoic Pan-African Trans-Saharan mobile belt that stretches from North Africa to Brazil, and has boundaries with the West African craton to the west and the Gabon-Congo craton to the southeast (Fig. 1) (Kennedy, 1964; Hurley and Rand, 1968; Hurley, 1968, Clifford, 1970; Caby *et al*, 1981; Torquato and Cordani, 1981; Boullier, 1991). It represents a terrain that was of considerable depth within the earth and has now been exposed by erosion of several millions of years (Oyawoye, 1972). Rocks occurring within the complex occupy about half of the total area that makes up the entire country (Cooray, 1974). These basement rocks are exposed in three main regions, namely southwestern region (De Swardt, 1953; Rahaman, 1973; Odeyemi, 1976, 1977; Annor, 1981); eastern region (Raeburn, 1927; Orajaka, 1964, 1971; Rahman *et al.*, 1981; Ekwueme and Ekwere, 1989; Ekwueme, 1990); and north-central region (Ajibade, 1972; Ogezi, 1977; Olarewaju and Rahaman, 1982) (Fig. 2). Earlier geologic studies on the crystalline basement complex of Nigeria were concentrated on the schist belts occurring in the western and north-central regions mainly because of the associated gold mineralization (Garba, 2000), and on the Younger Granite terrain in the north-central region due to the associated tin mineralization (Bowden and Kinnaird, 1984). Little or no detailed geologic investigation was conducted within the eastern basement complex. Consequently, the eastern basement complex appears to be the least in terms of available geologic information, when compared to the other two basement areas. The neglect suffered by this region was possibly caused by low density habitation and the prevailing thick rain forest which is a characteristic of the zone. The paucity of geologic information on most parts of the eastern basement complex of Nigeria has in the past led to ambiguity, over-generalizations, mis-information and mis-interpretations of the nature and crustal history of the entire basement complex of Nigeria. These have often been trailed by geological inconsistencies and divergence of views.

One very important basement terrain within eastern Nigeria is the Obudu Plateau, a vast N-S trending metamorphic terrain that constitutes part of the 3000 km - long Pan-African Trans-Saharan belt exposures in southeastern Nigeria, and suspected to be an extension of the Precambrian Bamenda Massif of Cameroon into southeastern Nigeria. Obudu Plateau is essentially characterized by the occurrence of regionally metamorphosed rock successions, pervasive migmatization and granite plutonism (Ferré *et al.*, 1996; Afaton et al, 1991). Preliminary reconnaissance geological mapping of the Plateau was carried out by Orajaka (1964, 1971), Umeji (1988, 1991) and Ekwueme (1991). More detailed studies covering the petrology, structural geology, geochemistry and geochronology of rocks of the Plateau have recently been conducted (see for example, Ejimofor *et al*, 1996, Ekwueme, 1990, 1994a, 1994b, 1998a, 2003a, Ekwueme and Kroener, 1997, 2000, 2001; Ekwueme and Matheis, 1993, Ekwueme *et al.* 1997, Ephraim, 1992, 2005; Ephraim et al., 2006; Ukwang, 1998; Ukwang *et al.*, 2003; Ukaegbu, 2003). Unfortunately, apart from Umeji (1988, 1991) and Ejimofor *et al.* (1996), all other studies were conducted on the crystalline basement rocks occurring within the southern region. Consequently, till date, not much geologic information exists on the northern region of Obudu. Until recently (Ephraim, 2005), the area of study, northeast Obudu, constituted parts of the areas that have never been geologically mapped in the northern regions of Obudu

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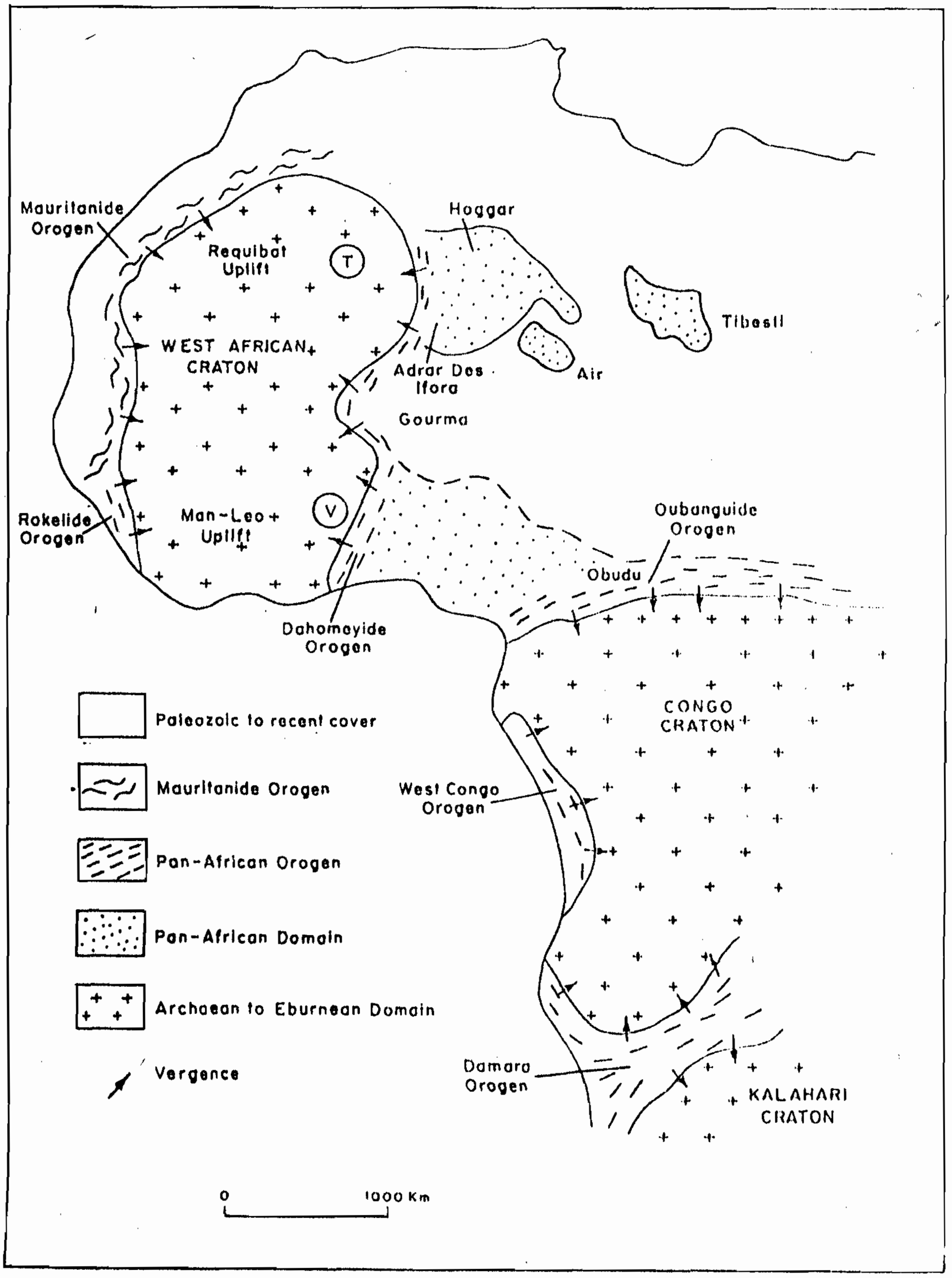

FIG. 1: A generalized geotectonic map of Africa showing the West African craton and the Congo-Gabon craton (note the location of Obudu area within the Pan-African domains) (Modified after Affaton *et al.*, 1991).

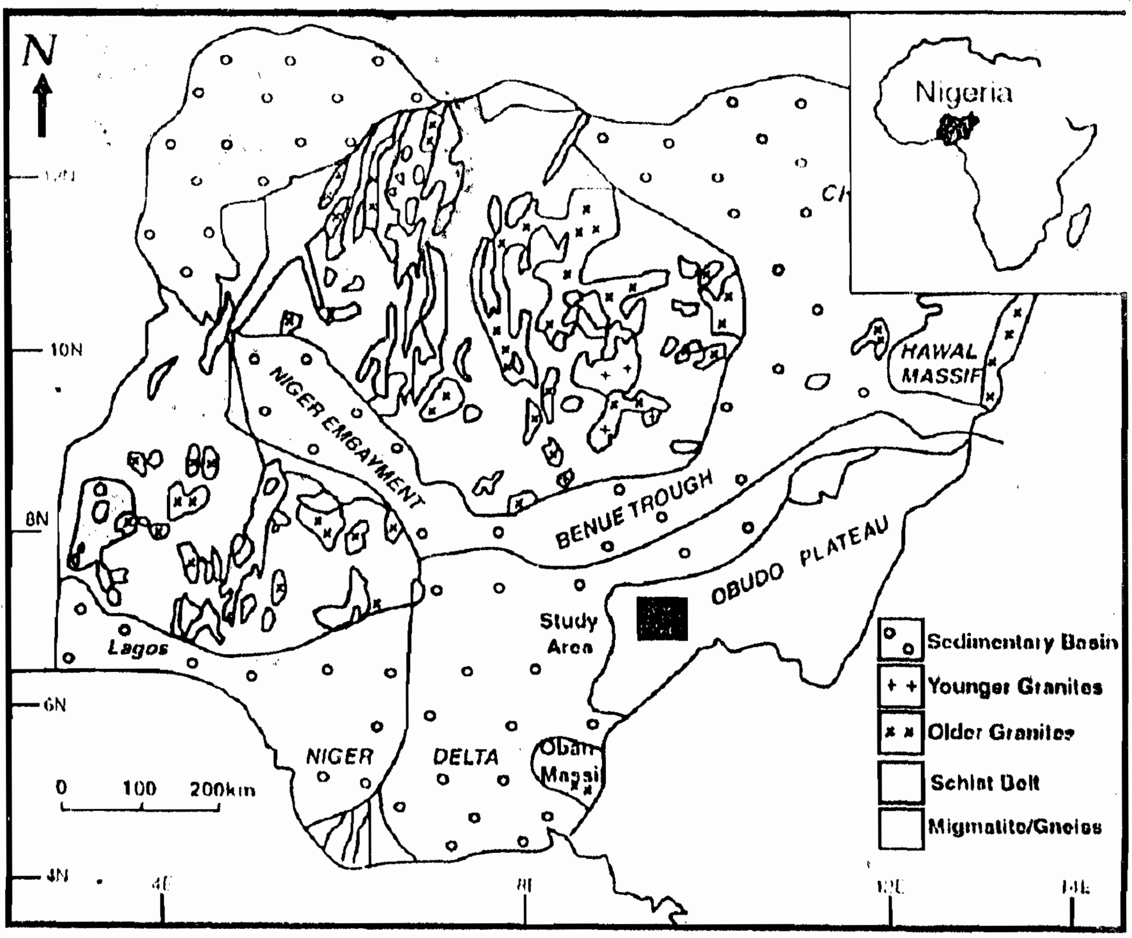

FIG. 2: Generalized geological map of Nigeria showing the distribution of the major rock groups and the location of the study area in southeastern Nigeria (Modified after Woakes *et al.* 1987 and Olarewaju, 1998).

It therefore became necessary that the northern region of the terrains be adequately investigated and the geology documented in order to have a better understanding of the geology of the entire Plateau. Such detailed studies will expectedly be devoid of ambiguity and over-generalization, and also guide comments on recent suggestions in the interpretation of the basement complex of Nigeria, such as those of Ferré *et al.* (1996, 2002) that the Nigerian basement complex comprises an amalgamation of at least two contrasting terranés, and Ekwueme (2003a) and Ephraim 2005) that the geology of southeastern Nigeria has more in common with Cameroon and the Central African fold belt than with northwestern and southwestern parts of the basement complex of Nigeria

In the present contribution, effort is made to present field, petrographical and mineralogical data on rocks occurring within the northeastern region of Obudu. Furthermore, these data are interpreted to bear on the nomenclature, classification, nature and origin, as well as on the tectono-metamorphic evolution of the rocks. The study will throw more light on the geology of the northern region of Obudu, which is most desirable considering the Plateau's position as a westward extension of the Precambrian Bamenda Massif of Cameroon into southeastern Nigeria (Udo, 1970; Ekwueme, 1998a).

DESCRIPTION OF STUDY AREA

The area of investigation covers approximately 784 square kilometers situated northeast of Obudu (Fig. 3) in the southern region of present-day Benue State of Nigeria. It is delimited by latitudes 6°45 and 7°00 N and longitudes 9°15 and 9°30 E, and enclosed within the Nigerian topographic Sheet 291 (Obudu NE). In terms of physiography, the area forms part of the westward extensions of the Cameroon-Adamawa Highlands (Udo, 1970). It has been subjected to extensive plutonism, and therefore has a typical landscape that is characterized by extensive high level plains that are interrupted by occasional sporadic isolated granitoid highlands. The prominent hills are located within the northern and southern regions. The central region appears to be barren of hills. The hills in the area commonly have oval to conical apices that appear to have been flattened by the combined effect of exfoliation and spheroidal weathering. The average elevation of the area is about 183 metres above sea level. Very high altitudes that may exceed 900 metres above sea level are obtainable in the southeastern region of the area. Two major rivers (Amire U Kiriki and Amire U Tamen) extend in a North-South direction at both the eastern and western portions. These rivers drain the area, which is almost devoid of small streams. Because the area is situated within the tropics,

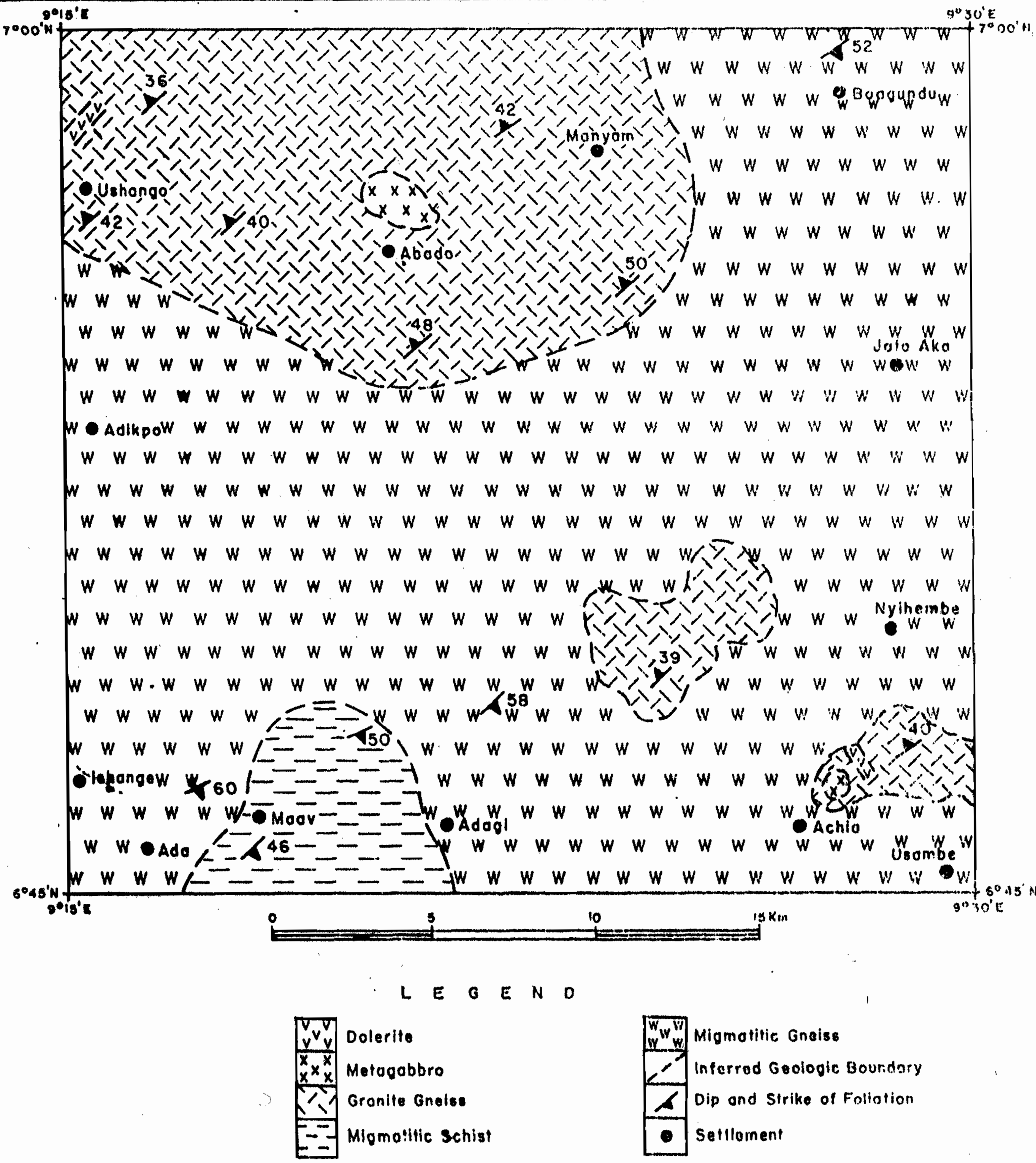

Fig. 3: Geological map of Northeast Obudu area, Bamenda Massif, Southeastern Nigeria

it has a climate that is characterized by the alternation of wet and dry seasons. The wet season starts from April and ends in October, while the dry season operates from November to March. The mean annual rainfall is approximately 2000 – 3000m, while the mean annual temperature varies from 14 – 28°C and the relative humidity is quite high (Udo, 1970; Duze and Ojo, 1977; Mabogunje, 1983). In terms of vegetation, the area like other parts of the Middle Belt is a zone of transition between the forested south and the Sudan Savanna. Here the high and luxuriant rain forests that are prominent features in the south have given way to less dense forests and a progressively more open savanna-type vegetation. The tops of the highland areas are usually covered with grasses and occasional light bushes, especially in the northern region of the area.

REGIONAL GEOLOGIC SETTING

The eastern basement complex of Nigeria comprises three major megastructural features that host Precambrian basement exposures, namely:

1. Oban Massif;
2. Bamenda Massif; and
3. Hawal Massif.

Although, basements in each of these massifs are bound to have some peculiarities that are not shared, the geology of the eastern basement complex is essentially characterized by the predominance of Pan-African intrusions and high-grade basement rocks such as migmatities, granite-diorite (Wright, 1971; Ferré *et al.*, 1995, 1996); and granulite facies gneisses, metapelite and calc-silicate rocks; as well as Jurassic alkaline granites (Bowden and Kinnaird, 1984). Rahman *et al.* (1981), Ekwueme and Onyeagocha, (1985a, 1985b, 1986), Ekwueme (1985, 1987), Rahman, *et al.*, (1988), Ekwueme and Ekwere (1989), Ekwere and Ekwueme (1991), Ekwueme and Caen-Vachette (1992), Ekwueme and Kroener (1995, 1998), Ekwueme and Nganje (2000), have stated that the massif is dominated by Uwet granodiorite and charnockitic masses. These rocks commonly intrude a sequence of gneissose and schistose rocks similar to those of southwestern and northeastern Nigeria (Ekwueme, 2003a). Low-grade rocks such as slate, phyllites and schists have also been mapped in the Akpet and Ugep areas of the Oban Massif (Ekwueme, 2003b)

Generally, the Obudu Plateau is composed dominantly of a floor of high-grade metamorphosed rock successions that are essentially quartzo-feldspathic gneisses and schists which exhibit migmatitic characteristics, and have been intruded at various locations by prominent plutonic rocks (Orajaka, 1964, 1971; Ekwueme, 1990, 1991, 1994a, 1994b. 1998a; Ephraim, 1992, 2005; Ejimofor *et al.*, 1996; Ekwueme and Kroener, 1997, 2000, 2001; Ukwang, 1998; Ukwang *et al.* 2003, and others).

Not much is presently known of the Hawal massif in the northeast, apart from the fact that the basement in this area is extensively intruded by granitic and charnockitic rocks (Rahaman, 1988), and that calc-alkaline plutonic suite that comprises diorite-granodiorite-granite and gabbroic rocks occurring between Hong and Mubi form the bulk of the Mandara hills and continue into western Cameroon (Ekwueme, 2003a).

FIELD RELATIONSHIP AND PETROGRAPHY

Crystalline rocks mapped in northeast Obudu area include, migmatitic gneisses, migmatitic schists, granite gneisses, metagabbro, dolerite and amphibolite (Fig 3). Thin sections of representative samples of each of these rocks have been studied under both polarizing and scanning electron microscopes. The scanning electron microscopy was performed at the Indiana University School of Dentistry/Oral Health Research Institute in the United States of America, and details are in Ephraim (2005). The average modal compositions of the rocks are presented in Table 1. Petrographic examinations of each of the rock types revealed the textural relationships of minerals in the rocks of the area. These textural relationships indicate that equilibrium assemblages were formed in the rocks. Detailed descriptions of the field characteristics, petrography and mineralogical composition of each of these rocks are summarized below.

Migmatitic Gneisses

Gneissose rocks of quartzo-feldspathic composition constitute the dominant rock type occurring within northeast Obudu area. Their occurrence and structural orientation are shown in Fig. 3. These rocks frequently exhibit migmatitic characteristics. The banding present in the migmatitic gneisses has been modified by shearing, injections of felsic materials, and by contortions or other complex folding patterns. Megascopically, the rock consists dominantly of the metamorphic host rock (palaeosome) and leucocratic acid injections (leucosome). The leucosome most commonly form layers or elongate lenses that is most often concordant to the foliation of the gneissose paleosome, giving the rock a somewhat banded or streaky appearance. The banding is often defined by the alternation of weakly mafic paleosome or melanosome and thin leucosome bands which varies from a few millimeters in thickness to several centimeters. These bands may be regular or discontinuous and sometimes form pinch and swell structures that are often conformable with the regional foliations or structural trend of the rocks of the area. They may also be contorted and folded, giving rise to tight to open folds within the rock. At some locations, the leucocratic melt-patches crosscut the foliation (Fig. 4), thereby distorting the banding. The foliation of the gneissic rocks is also frequently distorted by quartzo-feldspathic dykes and veins that commonly dissect the rock at various positions, giving it some kind of agmatitic appearance. The modal composition of the migmatitic gneiss presented in Table 1 confirms that the rock is quartzo-feldspathic in composition. Quartz and feldspars altogether make up more than 70% of the mode of the rock, while biotite, garnet and sillimanite occur as replacements/alteration products. The accessory mineral phases include zircon, rutile and opaque oxide. Traces of orthopyroxene have also been observed in some of the thin sections examined. Quartz consists of irregularly shaped crystals that have their lenticular outlines parallel to the fabric of the rock. Overgrowths are also common on the quartz and some of the crystals show twinning, while wavy or undulose extinction occurs in a less pronounced scale. Interstitial quartz is also present and together with the plagioclase constitutes the groundmass mosaic of most of the thin sections examined. The feldspars include both plagioclase and k-feldspars, even though plagioclase dominates. Plagioclase feldspars have a compositional range of An_{27} - An_{40} (oligoclase-andesine), and is generally colourless with some altered portions that constitute the exceptions. In terms of habit, the crystals are anhedral - subhedral and are sometimes untwined and therefore differentiated from the quartz by their alteration effects, especially to saussurites. Sericitization of the plagioclase minerals is rampant and is obvious from the rimming and inclusions of sericite minerals within the plagioclase minerals. K-feldspars are subordinate to both plagioclase and quartz minerals within the rock and they are dominantly orthoclase with very little or no microcline. Microperthitic intergrowths, mymerkitic and mortar textures are altogether absent in all the thin sections observed. Biotite makes up about 14% of the migmatitic gneisses volume, and appears to be of two generations. The early or first generation biotite displays anhedral slender and prismatic habit with occasional stumpy laths that may sometimes be kinked, whereas the late or second generation biotite plates are mainly isolated subhedral crystals that are tabular in form as well as randomly distributed, sometimes cross-cutting each other. Some of the first generation biotite crystals show alteration/replacements effect such as serrated and embayed margins. This variety of biotite is pleochroic from bright to brownish green colour and occurs in radiating clusters which are commonly aligned in mainly two preferred directions of orientation. In contrast, the second generation or late biotite crystals are generally clear and commonly pleochroic through yellowish to reddish brown colour. The biotite minerals, especially the first-generation type occasionally contain inclusions of apatite. Garnet crystals make up about 3.5% of the rock mode (Table 1) and are commonly wrapped around the foliation of the first generation biotite. In plane polarized light, these garnet crystals are brownish in colour, cracked and commonly exist as porphyroblast that are sometimes fragmented. They also exhibit poikiloblastic textures that are characterized by the inclusions of fine crystals of quartz, biotite and opaque oxides. Where garnet crystals occur adjacent to biotite, the early-biotite frequently shows replacement features, whereas the late-biotite commonly persists undeformed.

TABLE 1. *Modal compositions and mineralogical assemblages in rocks of northeast Obudu*

	Migmatitic Gneiss N* = 10	Migmatitic Schists N = 6	Granite Gneiss N = 12	Metagabbro N = 5	Amphibolite N = 2	Dolerite N = 2
Quartz	29.6	28.2	28.4	-	6.5	-
Plagioclase	26.7	24.8	22.4	22.2	25	42
K-Feldspar	18.6	13.3	33.3	1.4	3	-
Biotite	14.2	20.7	12.3	3.4	9.5	-
Muscovite	-	1.8	-	-	-	-
Hornblende	-	tr	-	6.2	50.5	-
Garnet	3.5	9.5	-	-	-	
Sillimanite	3	0.5	-	-	-	-
Epidote	2	1.2	0.4	-	1.5	-
Chlorite	-	tr	1.7	-	-	-
Sericite	1.2	-	tr	-	-	-
Orthopyroxene	Tr	-	-	43.8	-	38.5
Clinopyroxene	-	-	-	19	-	8
Olivine	-	-	-	2		9
Sphene	Tr	tr	tr	-	1	
Zircon	Tr	tr	tr	-	-	-
Apatite	0.2	-	tr	-	-	-
Iron Ore	0.9	-	tr	2	3	2.5
TOTAL	100	100	100	100	100	100

*N = *No of samples analyses*

Fig. 4: Leucocratic - melt patches cross – cut foliation in a migmatitic gneiss outcrop occurring in Northeast Obudu

Sillimanite crystals also occur within the rock as a minor constituent of about 3% (see Table 1). They are generally observable as finely felted fibroid aggregates of acicular fibrolite that form contorted lenses. Sometimes they appear to be growing on biotite crystals. In addition, traces of orthopyroxene occur in textural equilibrium with the already mentioned assemblages

Migmatitic Schists

Several varieties of schistose rocks constitute another major rock types occurring within Northeast Obudu (see Fig. 3). Like the gneissic rocks, the schistose rocks are frequently migmatitic and formed parts of the basements into which felsic and mafic plutons were intruded. They occur within the south-central regions of northeast Obudu adjacent to the migmatitic gneisses and extend outside the mapped area southwards. In addition, small scattered masses of medium to high - grade schists have been observed to occur as pods and extensive sheets within the granite gneisses in spite of the fact that elsewhere the orthogneisses and schistose rocks do not have any contact relationship. Most outcrops of migmatitic schists within northeast Obudu are extensively weathered and in some places such as within the Amiri U Kiriki river bank and channel, the schists are conspicuously layered, occasionally displaying relict grading, well preserved beddings and syn-sedimentary deformational structures. These rocks are also frequently associated with quartzitic selvages and ridges similar to the type that occur in the migmatitic gneisses of the area.

The migmatiitic schist in the area have well-developed schistosity, and in hand specimen, the schist is greasy and soft to the feel. They are generally characterized by their greyish colour, medium to coarse grained texture and fair segregations into light and dark bands that correspond respectively to the leucocratic and mesocratic mineral-rich phases. The schistose rocks often include 1 – 2 cm thick parallel mafic and felsic layers that form clearly defined leucosomes and melanosome. Both mafic and felsic layers of the rocks are medium-grained, with granoblastic-polygonal textures. As such, these rocks are stromatic migmatites that can as well be classified as "low-grade migmatites" (Brown 1979).

No contact relationship was observed in the field between the migmatitic gneisses and schists, but spatial configurations of both rock types suggests that the schists may be relatively younger and were probably supracrustals on the gneissic rocks of the area. However, it is only geochronological data that can lead to a better conclusion on the chronology and structural relationship between these two types of rocks within the area.

The modal compositions of the migmatitic schist presented in Table 1 show that the leucocratic mineral-rich phases of the rock include quartz, plagioclase, and K-feldspar, whereas the mesocratic regions is commonly made up of biotite and garnet, and probably minor concentrations of sillimanite, epidote and muscovite. Chlorite, sphene and titanite constitute the accessory mineral-rich phase with less than 1% contribution to the rock mode. The feldspar minerals present include both plagioclase and K-feldspars. The former dominate with an average composition of about 25% (see Table 1). The plagioclase minerals have a compositional range of An_{25} - An_{30} (Oligoclase). Oligoclase comprises anhedral to subhedral crystals that are not necessarily twinned but commonly contributing to the formation of the groundmass by occurring in a matrix of interlocking grains with quartz and subordinate K-feldspars Sericitization of the oligoclase occurs in a small scale and is indicated by the rimming and inclusions of sericite minerals within the plagioclase. K-feldspar is subordinate to plagioclase and in some thin sections; orthoclase dominates, while in others, microcline is the dominant K-feldspar. Yellowish to reddish brown biotite is the dominant mafic mineral present. They are often associated with garnet and sometimes minor muscovite. The biotite occurs in a wide variation of sizes from porphyroblasts to narrow small plates of matrix sizes with some of the crystals kinked. Although dominant, the biotite crystal most often occurs in isolation with well-defined orientations Some crystals also occur intersperse within the groundmass and as inclusions in other minerals. Garnet occurs consistently in all the thin sections of migmatitic schists examined The grains are mostly porphyroblastic with subhedral outline. Sometimes the garnet grains exhibit embayed margins and often harbour lots of inclusions of mostly quartz, mica minerals and opaque oxides. Sillimanite occurs as acicular fibrolite in some thin sections, and make up a minor component of the rock They often appear to be growing on biotite grains.

Granite Gneiss

Granite gneiss is well exposed as oval or dome-shaped outcrops sporadically distributed in the basement complex at both the northern edge and the southeastern regions of the study area. Despite the isolated nature of the rock, it is clear from field observations that they once belonged to a coherent plutonic body that underlies the area. The granitoid bodies have a dominantly north-south trending long axis, and are completely surrounded by migmatitic gneisses at both regions where they are exposed. They also form topographic highs, and display intrusive contact relationships with the country rocks. The narrow contact aureoles they display are usually slightly chilled with, some baking of the country rock often being evident at or near the contacts. Seven large granite gneiss outcrops were investigated and mapped in the area. With very few exceptions, each outcrop generally exhibits similar features, and exfoliation weathering has affected them, giving rise to a large-scale sheeting or peeling of the rocks. The result of such weathering is that joint-bounded concentric shells of the rock and large fragmental boulders that appear to lie *in-situ* are rampant and constitute parts of most of the exposures.

Each outcrop is typically made up of fine- to medium-grained granite gneiss near the marginal areas where it is difficult to distinguish with the surrounding migmatite gneiss complex due to the presence of narrow contact aureoles within the country rocks. The grain size increases very slightly inwards into the core of each of the outcrops. Within the core or central regions of the plutonic bodies, they are numerous well formed or euhedral porphyroblastic crystals that are dominantly orthoclase and plagioclase. The granite gneiss is generally homogeneous and weakly to strongly foliated. The rocks of Ushongo region host a number of medium to large veined gneisses and xenoliths of probably amphibolitic, gneissose, schistose or even reworked granitic materials in various random orientations. Rotations and relative displacements of blocks of these veined gneisses and xenolithic materials, sometimes resulting in the occurrence of minor faults with throws of about 20 to 65 cm within the host rock, have been observed in the field. The xenoliths, occurring as pods or sheets that have been subjected to variable degree of homogenization, commonly display sharp margins.

The granite gneiss in the area has been extensively dissected by a network of intersecting or crosscutting quartzo-feldspathic stringers or veins/veinlets of various widths and orientations, and the ones that are associated with outcrops in the southeastern margin of the area are not as numerous as those of the northern region These veins are dominantly composed of quartz and feldspar minerals The rock has also been invaded by numerous sheeted dykes of both mafic and felsic compositions Some of these have been slightly displaced. Joints within the granite gneiss trend dominantly in the ENE-WSW direction and sometimes these joints develop into rock pits. Weeds often grow on the joint planes, thereby making it easy to delineate zones of weakness in the granite gneiss

The contact between the granite gneiss and the country rock is best developed at Manor village in the northern region, and Usambe Village behind Binda hills in the south It is generally sharp and intrusive with narrow contact aureole.

There is evidence to show that there must have been a significant shattering of the country rocks sometimes in the evolutionary history of the rock.

The modal composition of the granite gneiss presented in Table 1 indicate that the feldspars altogether constitute more than half of the rock volume, followed by quartz and biotite, while chlorite and epidote taken together constitute barely 4% of the rock. The accessory-mineral phase comprising allanite, muscovite, sphene, zircon apatite and opaque oxides make up less than 1%. Apart from being the most dominant, the feldspars also exhibit the most striking petrographical and mineralogical features and are easily identifiable by their lath-shaped crystals and polysynthetic twinning. These minerals include variable proportions of K-feldspars, which are mainly microcline and plagioclase with a compositional range of An_{32}-An_{40} (Andesine). These commonly form euhedral to subhedral laths and plates that are randomly distributed showing no preferred orientation but most often contributing to the groundmass of the rock. Microcline generally forms the bulk of the rock and indeed the total rock composition with an average modal estimate of about 33%. It occurs sporadically in the field as large white to pinkish megacrysts and rhomps that may measure up to 5cm by 4cm, giving the rock a characteristic porphyroblastic appearance. Apart from microcline, euhedral laths of subordinate orthoclase have also been identified in thin sections of the rock. Microcline is easily identified by its well developed cross-hatched polysynthetic twinning, whereas orthoclase occurring in a lesser amount displays simple Carlsbad twinning. Some of the microcline crystals exhibit predominantly weak indistinct or diffuse zonation and the large crystals are occasionally cloudy with inclusions of mostly quartz, biotite and plagioclase that appear to be randomly distributed. Plagioclase feldspar (andesine) is subordinate to the K-feldspar with an average modal composition of about 22% (Table 1). The andesine crystals are characteristically colourless and typically exhibit a tabular subhedral habit with mainly serrated margins. In addition, some of the plagioclase crystals display secondary twinning in which their regularly spaced twin lamellae are bent and wedged out in a characteristic systematic manner. Zoning in the plagioclase occurs in a small scale and affects mostly the larger plagioclase crystals, while mantling relationships and intergrowths among the feldspars and probably quartz are rampant. K-feldspars commonly form microperthite intergrowth with the plagioclase and is equally involved in mymerkitic association that also includes quartz. It is, however, worth mentioning that no antiperthite intergrowth was observed in any of the thin sections of granite gneiss examined. It is also necessary to report that various forms of slight alterations such as seritization and saussuritization commonly affect the feldspars within the granite gneiss.

Quartz ranks next to the K-feldspar with an average modal composition of about 27%, and generally exhibits a porphyroblastic habit. There appears to be of two generations; early quartz occurs as rounded to sub-rounded crystals that occur in interstitial spaces, fracture planes and as inclusions in the feldspar minerals. They are often viewed as localized granoblastic aggregates that show regular extinctions and rarely exist as vermicular intergrowths with the feldspar in the formation of mymerkites. These early quartz are the ones that pair with the feldspar to form the granoblastic groundmass mosaic that displays triple junction contacts. The later quartz commonly occur as anhedral of irregularly shaped composite granoblastic crystals that are elongated parallel such that they appear to contribute to the linear fabric of the rock. This later variety most likely represents recrystalised quartz with overgrowths and the crystal normally exhibit undulose extinction and subgrain features. The later quartz crystals often display mortar textures in a small scale and are commonly studded with inclusions.

Biotite appears to be the major mafic mineral present in the rock and it constitutes about 12% of the rock. Like quartz, the biotite crystals are of two varieties; the tabular and light to dark brown euhedral crystals that most likely represent late or recrystallised biotite, and the predominantly anhedral, yellowish to reddish brown with greenish tint specks variety that occurs in radiating aggregates. These biotite crystals commonly define two major trends of preferred orientations and most often the later or recrystallised biotite appears to cross-cut the earlier variety.

Chlorite, epidote and sericite are clearly displayed as replacement or alteration products in all the thin sections of the rock studied. The chlorite crystals are commonly sandwiched between two biotite flakes, while sericite and epidote often occur as inclusions within the feldspars as well as along the edges of some of the feldspars. Epidote may be accompanied by apatite or allanite. Other accessory minerals present in the rock include titanite, rutile, opaque oxides and zircon. Most often, these minerals occur as inclusions within the essential minerals.

Metagabbro

Mafic rocks of essentially gabbroic composition occurs at both the northern and southern regions of the study area in close association with the granite gneiss. The rock has been metamorphosed and at both locations it occurs as lenticular to ovoid-shaped bodies. In some locations, exposures of the rock exist as scattered boulders. Although no contact relationship with the country rocks has yet been observed, spatial configuration suggests that outcrops of the metagabbroic rock can best be classified as concordant bodies. That of the northern region, which constitutes the Nto hill, measures approximately 1.5 km by 1.0 km, and is elongated in the NNW-SSE directions. Moreover, it is much more prominent in terms of exposures, compared to that of Kpe hills in the south. Exposures of metagabbroic rock of Kpe Hill dominantly occur in the form of stumps on the hilltop, together with scattered boulders of similar composition. Mesoscopically, the metagabbroic rock is coarse-grained and weakly foliated.

The petrographic feature of the metagabbroic rocks is still being investigated. However, the modal composition of the rock presented in Table 1 show that the rock contains plagioclase, which is of compositional range An_{42}-An_{42} (andesine), orthopyroxene, clinopyroxene, hornblende, and biotite, while olivine, opaque oxides, and K-feldspar occur in minor concentrations. Plagioclase occurs as elongate to tabular plates, with broad albite and minor Carlsbad twins. They are frequently schillerized and partially altered/ replaced by mostly minerals of the epidote group (epidote, zoisite and clinozoisite) in association with calcite, in a process that is referred to as sassauritization (Hatch *et al.*, 1979, Mange and Maurer, 1992). Also, the plagioclase is often involved in the formation of sub-ophitic texture with the pyroxene.

Dolerite and Amphibolite

Dolerite and amphibolite constitute the minor rocks of the area. The dolerite occurs as intrusions into the granitoid, while the amphibolite occurs as unmappable enclaves within the granite gneiss. The only dolerite mapped within the area intrudes the granite gneiss of Ushongo area with sharp contacts. The second occurs as large boulders, associated with boulders of metagabbroic rocks on Kpe hill in the southern region of the area.

Mesoscopically, the dolerite is fresh, dense, dark in colour, and generally fine-medium grained. It does not show any effect of hydrothermal or deuteric alterations and exhibits ophitic to sub-ophitic texture. Moreover, the dolerite is largely unmetamorphosed, undeformed and commonly displays chilled margins with its granite gneiss host. It has an orientation that is consistently in the NE – SW direction. The amphibolite, on the other hand, occurs within the granite gneiss of northeast Obudu as bands or lenses of variable dimension and orientations. Sometimes the bands are sheared and deformed to produce dismembered enclaves within the host rock. The amphibolite is typically dark grey in colour, fine – medium grained, and slightly foliated. The orientations of the enclaves are not consistent; some are discordant, while others are concordant to the regional N-S foliation of the area.

The modal compositions in Table 1 show that the dolerite is essentially composed of plagioclase with a compositional range of An_{40} - An_{46} (andesine), orthopyroxene of variable sizes and shapes, clinopyroxene and olivine. The accessory mineral phase is mainly opaque oxides. The lath-shaped plagioclase minerals are randomly oriented, and occur in ophitic to sub-ophitic relationships with the pyroxene minerals. The modal composition of representative samples of the amphibolitic rock also presented in Table 1 shows that the rock is generally made up of about 50% hornblende, 28% plagioclase, 9-10% biotite and less than 10% quartz, as well as opaque oxide, epidote and sphene.

DISCUSSION AND CONCLUSIONS

Field and petrographic investigations reveal that apart from dolerite, all other rocks mapped in northeast Obudu area have been metamorphosed to various grades. This could have significant implications on element mobility between each of the rock types, but extensive studies on metasedimentary and meta-igneous rocks worldwide suggest otherwise (Rollinson, 1993; Holland and Winchester, 1983; Ferry, 1982; Dostal *et al.*, 1980; Clough and Field, 1980; Shaw, 1956; Okonkwo and Winchester, 2000). These studies agree that isochemical metamorphism, involving no whole-sale element mobility apart from loss of water and other volatiles, are valid in large rock systems that have been metamorphosed, unless the rocks were subjected to granulite facies metamorphism and/or extensive mylonitization, or contain significant amount of carbonate rocks. However, since none of the above conditions hold for rocks of Northeast Obudu area, it is reasonable to assume that the rocks were subjected to isochemical metamorphism.

The inter-banding with quartzitic layers and lenses observed in the migmatitic rocks of the area clearly portray the rocks as metasediments. Ekwueme (1991) observed interbanding, on a megascopic scale, of garnet silllmanite gneiss with quartzitic units, and explained such occurrence to be indicative of the sedimentary parentage of the rocks. Another feature that also indicates the sedimentary nature of the protolith of the migmatitic rock of the areas is the occurrence of pelitic index minerals, such as sillimanite and garnet among the modal minerals of the rocks

Field evidence points to the fact that the granite gneiss of the area are of magmatic parentage. One of the mechanisms of emplacement of the parent igneous rocks of the area was by piecemeal stoping. This is because the granitoids commonly incorporates numerous blocks of the country-rocks, which are often associated with slight displacements and/or rotations (Ehlers and Blatt, 1982). The incorporations of xenolithic blocks by granitoids often gives indication of the mode of emplacements of the rock (Hatch *et al.*, 1979).

The intrusion of dolerite appears to be the youngest event in northeast Obudu area for two main reasons, namely:

1. This rock type is the only one that is unmetamorphosed compared to other mapped and,
2. The rock type intruded granite gneiss through pre-existing fractures.

There appear to be a lot of similarities between dolerites from northeast Obudu area and those of the southern region. For instance, they are both unmetamorphosed and show no effect of deformation, their outcrop at both regions trend generally in the NE – SW region indicating that they are both structurally controlled. They are both closely related with subordinate amphibolite in the field. For these reasons, dolerites from both the northeast and southern regions are most likely genetically related. Similar conclusion can be reasonably adopted for all other rocks types occurring in northeast Obudu, considering their characteristics features and location.

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