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PETROLOGY OF GRANULITE FACIES ROCKS IN UKWORTUNG AREA OF OBUDU PLATEAU, SOUTHEASTERN NIGERIA

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ABSTRACT

Rocks of the Ukwortung area of Obudu, southeastern Nigeria consist of pyroxene –biotite –, garnet-biotite-gneisses and meta-utramafite. These rocks were intruded by various granites and pegmatites during the pan-African thermotectonic event. The presence of hypersthene, plagioclase (An_{38-46}), hornblende and antiperthitic intergrowths in the rocks of Ukwortung indicates uppermost amphibolite to granulite facies metamorphic conditions were attained. This high –grade metamorphism was followed by retrogression to amphibolite facies grade.

INTRODUCTION

The Nigerian basement complex is part of the Pan-African mobile belt situated between the West African Craton to the west and the Gabon – Congo Craton to the southeast (Kennedy 1964, Clifford 1970, Turner 198).Rocks of the basement complex in Nigeria comprises of migmatite-gneiss-quartzite complex and meta-volcanosedimentary series intruded by an Older Granite suite (McCurry 1976; Rahaman 1976; Oyawoye 1972 ;Ekwueme and Onyeagocha 1985). At least two episodes of deformation contemporaneous with or prior to the tectonothermal events have been recognized in the Nigerian basement complex (Oyawoye,1972; Rahaman 1976;Ekwueme1987). Metamorphism in the basement complex is either Barrovian or Buchan types (Rahaman, 1976;Oyeagocha 1979)

This present study of the basement complex is the western part of the Nigerian topographic sheet 291 (Obubu S.W.) lying between latitudes $6^{0}30^{1}$ and 6^{0} 41^{1} and longitudes $9^{0}00^{1}$E and $9^{0}08^{1}$E. (Fig 1). Its aim is to present a preliminary account of the petrographic relationships in granulite facies assemblages of the Ukwortung area.

PETROLOGY OF THE AREA

The common rock types of the Ukwortung area are migmatites, gneisses, amphibolites meta-ultramafites and quartzites(Fig.1).

Gneissic rocks are found to cover more than half of the Ukwortung area; of all these, pyroxene gneiss forms the dominant rock type (Fig. 1). The migmatite gneiss and the garnet-biotite gneiss occur toward the eastern margin (Kakum – Bedia region) of the area (Fig. 1). The migmatite gneiss and the garnet-biotite gneiss exhibit abundant ptygmatic, isoclinal and open folds (Fig. 2) with the most dominant foliation corresponding to the north south Pan – African trend.

The pyroxene- bearing gneiss covers the area extensively (over 35km^{2}) and completely surrounds the meta-ultramafic body at Ukwortung (Fig. 1). Towards the Ukpe – Bedia region, the pyroxene gneiss is in contact with biotite gneiss. Banding is prominent in certain localities (like Mkpenege with leucocratic bands) and ranges

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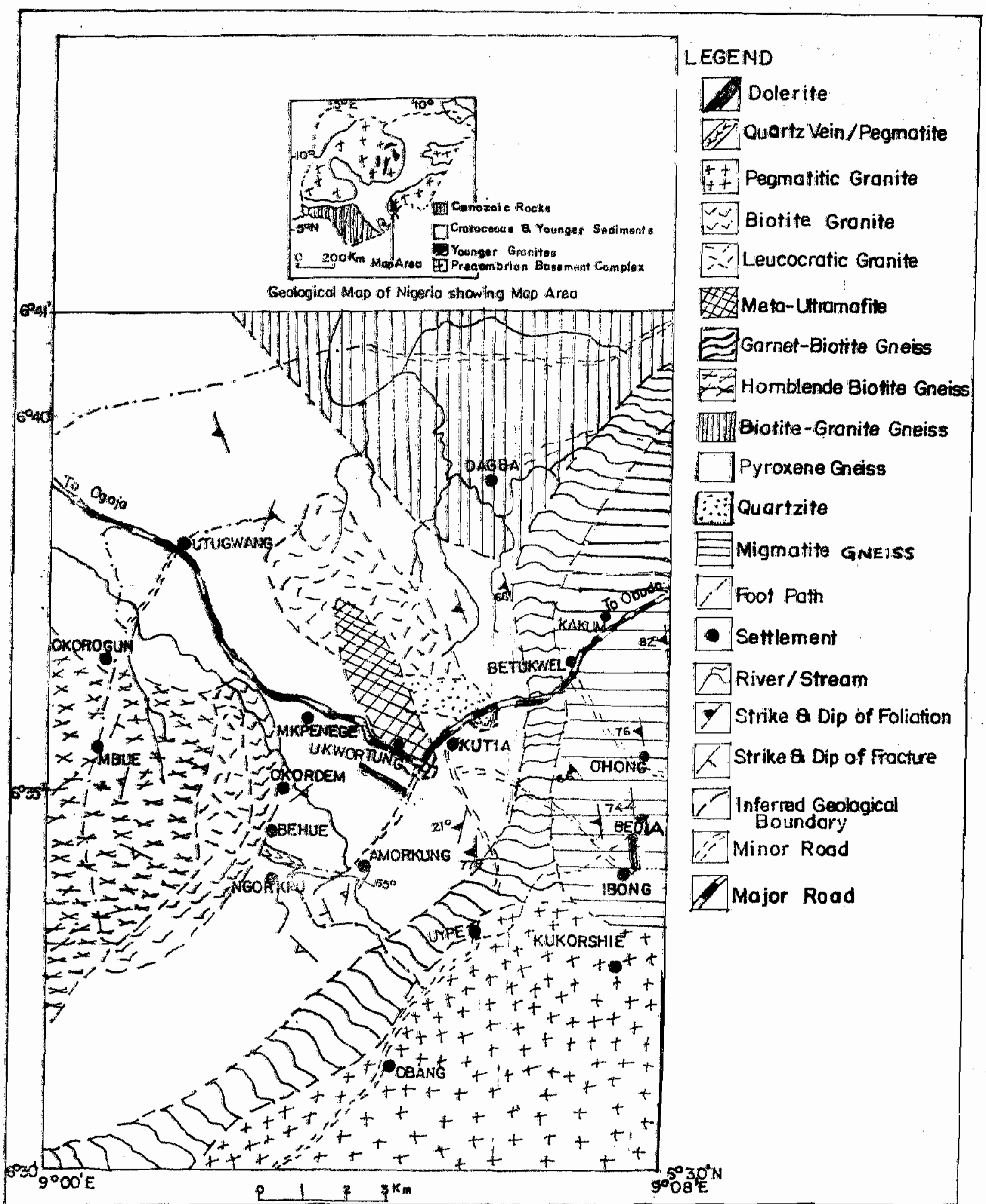

FIGURE I: GEOLOGIC MAP OF UKWORTUNG AND ENVIRONS, OBUDU S.W. NIGERIA.

Fig. 2: Open and Isoclinal folds in mignatite gneiss at Kakum

Fig. 3: Relict of amphibolite wrapped around by foliations of the host gneiss at Ukwortung

from coarse to pegmatitic in texture. Occurring within the gneiss complex are more mafic rock types (amphibolites) with foliations of the host gneiss wrapping around them (Fig. 3). The foliation pattern is merely a result of the amphibolite being more competent in nature. The contact between the amphibolite and the host is mostly gradational with the mafic rock having a coarser texture closer to its margin (Fig. 3)

Generally, the pyroxene gneiss is mesocratic with deformation structures such a foliations, pinch and swell structures (Fig. 4), fracturing, and faulting much in evidence. Partial melting resulted in the formation of finer grained mesocratic bands and coarser grained leucocratic bands which are highly foliated. The squeezed out quartzo-feldspathic material forms coarser pegmatitic portions which have been deformed into boudins and slightly sheared in some localities (Fig. 4). Hence, the rocks of the area have been subjected to a high degree of metamorphic segregation into bands.

PETROGRAPHY

The modal composition of the pyroxene gneisses is shown in Table 1. It indicates that quartz is abundant. Grains of quartz showing wavy extinction occur both as inclusions and porphyroblastic crystals having inclusions of hornblende, pyroxene and opaque minerals. Quartz is less abundant in the variety of pyroxene gneiss that contains no biotite. Generally, the quartz crystals have no subgrain structure.

Plagioclase in these medium grained rocks exhibits twinning on the albite and pericline laws, carlsbad twins are rare (Fig. 5). The subhedral grains and those with grain boundaries slightly curved and embayed show undulose extinction. In vicinities such as Ukwortung and Okorogun, plagioclase crystals show antiperthitic intergrowths of alkali feldspar. The plagioclase composition ranges from An_{38} to An_{47} (andesine). Biotite grains are subhedral and tabular in shape. These strongly pleochroic grains along with hornblende define a poor foliation in the pyroxene gneiss under the microscope. Biotite is absent in some samples from Ukwortung-Okordem axis. Two generations of biotite are observed. The first generation is tabular and strongly pleochroic from pale yellow to reddish brown and defines the foliation. The second generation is euhedral in form, reddish brown in colour and strongly pleochroic from reddish brown to dark brown. These grains are randomly oriented. (Fig. 6).

The modal composition also indicates

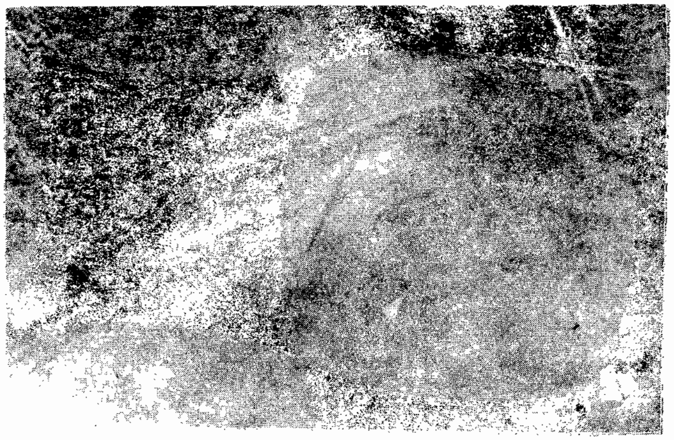

Fig. 4: Deformation structures in pyroxene gneiss pinch and swell structures as well as sheared boudin close to pencil

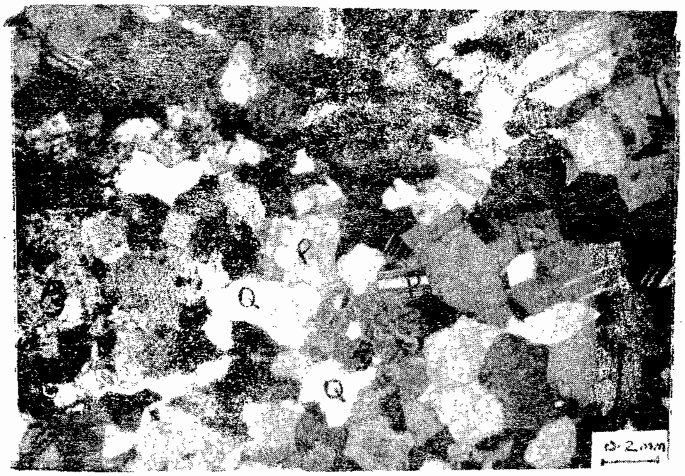

Fig. 5: Photomicrograph of pyroxene gneiss P = plagioclase; Q = quartz; Py = Pyroxene (under crossed nicols)

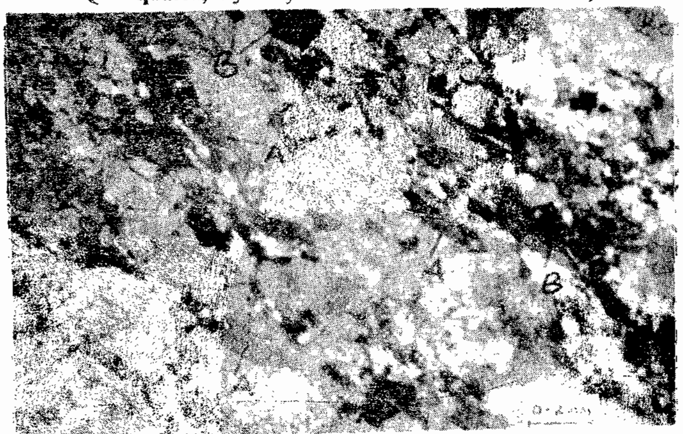

Fig. 6: Photomicrograph showing two generations of biotic. A = 1st generation; B = 2nd generation (under crossed nicols)

hornblende is common. The grains are mostly subhedral and strongly pleochroic from yellowish green to light brown. Pleochroic scheme:
X = Yellowish green, Y = Light brown,
Z = Brown. Absorption scheme: X <Y < Z
Crystals of hornblende that show parallel cleavage have extinction angles between 14^0 and 24^0. In contact with quartz or feldspar, the hornblende grains exhibit light rim probably due to alteration to lower grade amphibole (Fig. 5).

Pyroxene occurs with or without biotite in some samples. The grains show relief with anhedral to subhedral forms (Fig. 5). The pale reddish coloured grains show faint pleochroism from pale pink to pale yellowish colour; pleochroic scheme is as follows:
X = Pale pink, Y = Very light pink and Z = Pale yellow. Absorption. Z < Y < X

The optically negative character suggests it is hypersthene. The extinction is almost parallel to cleavage traces with angle of about 12^0. These hypersthene grains are rimmed with a paler margin when in contact with quartz and feldspar (Fig. 5). The paler portions are probably due to recrystallization to amphibole (uralite) (Deer et al., 1978).

Clinopyroxene occurs in lesser proportion than orthophroxene, with no exsolution of orthopyroxene being observed. These colourless, anhedral grains are smaller in size than the orthopyroxene. The clinopyroxene grains exhibit high relief with moderate birefringence. Clinopyroxene tends to be interstitial compared to the orthopyroxene which occasionally form large poikiloblastic grains. Inclusions in the orthopyroxene include quartz, orthoclase, clinopyroxene and plagioclase.

Accessory minerals include apatite as tiny inclusions in hypersthene, sericite resulting from the alteration of plagioclase and zircon which shows pleochroic haloes within the biotite crystals. Spinel occur as discrete grains and also as inclusions in hornblende; it is the rounded, globular green variety suggesting hercynite

Opaque minerals occur as subhedral to anhedral grains. These xenomorphic grains in some cases contain inclusions of other minerals e.g. hornblende.

GEOCHEMISTRY OF THE GNEISSES:

Major elements analysis was carried out at the Institute of Oceanography, University of Calabar in collaboration with the Central Laboratory at the University of Uyo. Analytical procedure used involved digesting 1g of pulverized rock sample with a mixture of 80% HNO_3 and 40% H_2SO_4 in the ratio of 1: 2 for 3 to 4 hours. The concentrated digest is diluted with deionised water to 1.0 litre. Aliquots were taken and analysed for specific metals after due calibration using salts of metals to be analysed. The molar concentrations (in ppm) of the metals were obtained by direct reading using DREL 300 spectrophotometer (Precision = 0.0001%). Major ions (Na, Ca, etc) were obtained from EDTA (Ethylene Diammine Tetra –acetic Acid) titremetry method. K concentrations were obtained as a difference in the summation of major cations and anions. L01 was determined as loss in weight by ignition 0.5g of sample between 350 –500°C using a kalin muffle furnace. Weight percent was calculated from the molar concentrations of the respective metals. Confirmatory analysis was conducted at the Nigerian National Petroleum corporation (NNPC) laboratory in Port Harcourt using an Atomic Absorption Spectrophotometry (AAS). The results are presented in Table 2.

Pyroxene gneisses of Ukwortung area differ from the hornblende – biotite gneiss in terms of the high proportion of total iron (Fe_2O_3+FeO) and MgO in the former. The large proportion of ferromagnesian minerals truely reflects this.

Pyroxene occurs in the norm as well as in the mode (Tables 1 and 2). The silica content is moderate and ranges from 52.00 to 55.00 wt. % (Table 2). The average CaO and MgO contents are 6.89 and 7.82 wt.% respectively.

The average CIPW normative values for magnetite and hypersthene are 5.88 and 25.20% respectively. These values are supportive of the high FeO and Fe_2O_3 for the rock. Normative quartz for the pyroxene gneiss on the average is 2.26%. The alkali (Na_2O+K_2O) is approximately 4.78. These values are reflected in normative albite and

Table 1: Average Model Compositions (Volume %) of the Gnisses Ukwortung Area, Obudu Plateau, S.E., Nigeria

	Pyroxene Gneisses			HbL - Biotite Gneiss	Garnet Biotite Gneiss
	HbL - Deficient (6 Samples)	Cpx - Deficient (7 Samples)	Biotite - Deficient (4 Samples)	(4 Samples)	(4 Samples)
Quartz	25	20	7	25	27
Plagioclase	14	—	22	17	25
K-feldspar	—	8	—	13	13
Orthopyroxene	15	12	23	—	—
Clinopyroxene	5	—	12	—	—
Biotite	24	12	—	19	20
Hornblende	—	25	30	11	—
Garnet	—	—	—	—	9
Opaques	5	3	5	6	4
Spinel	3	2	—	5	—
Apatite	4	3	—	—	—
Zircon	—	2	—	—	—
Sericite	1	5	—	—	—
Chlorite	1	—	—	—	—
Epidote	—	4	—	—	—
Sphene	2	2	—	—	—

Table 2: Chemical Analyses of Gneisses In Ukwortung Obudu Plateau, S. E., Nigeria.

Sample No	OD711	UN 522	OH	OG1	OG2	OK 607	KT 403 Kutia	UW 512	UW504
Location	Okordem	Ukwortung	Bedia	Okorogun	Okorogun	Ukwortung		Ukwortung	Ukwortung
OXIDES		PYROXENE		GNEISS			HORNBLENDE	BIOTITE-GNEISS	
SiO_2	55.00	53.63	54.14	52.00	55.20	54.13	61.00	63.00	58.34
Ti02	0.41	0.57	0.43	0.75	0.52	0.60	0.45	0.58	0.42
AL203	12.14	12.92	12.17	9.14	9.34	8.22	10.75	10.9	11.45
Fe03	3.13	3.11	1.73	7.03	3.81	5.44	2.43	3.43	5.02
Fe03	9.05	8.52	10.06	12.36	10.18	10.83	11.10	7.03	10.18
Mn0	0.01	0.03	0.02	0.02	0.04	0.22	0.03	0.03	0.09
Mg0	8.08	6.65	8.40	8.77	6.28	8.65	2.86	2.36	2.73
Ca0	6.43	8.20	7.41	5.36	7.44	6.52	6.44	5.08	5.28
Na20	2.18	2.56	2.25	3.56	3.37	3.26	2.39	1.81	2.25
K20	3.37	2.22	2.36	0.35	1.92	1.25	1.36	5.07	3.39
P205	0.02	0.04	0.23	0.14	0.27	0.05	0.15	0.1	0.26
LOI	0.32	0.05	0.50	0.52	0.51	0.50	0.53	0.47	0.49
Total	**100.14**	**99.31**	**99.71**	**100.00**	**98.99**	**99.87**	**99.85**	**99.86**	**99.9**
Niggli	**Values**								
Al	18.00	20.00	18.00	13.00	14.00	12.00	20.00	22.00	20.00
Fm	55.00	47.00	54.00	64.00	52.00	62.00	48.00	42.00	49.0
C	17.00	23.00	19.00	14.00	21.00	17.00	22.00	19.00	17.00
Mg	0.47	0.58	0.600	0.42	0.53	0.58	0.32	0.38	0.32
Alk	11.00	10.00	9.00	9.00	12.00	9.00	10.00	17.00	13.00
K	0.61	0.36	0.40	0.07	0.27	0.20	0.26	0.64	0.49
Si	137.00	138.00	132.00	127.00	142.00	128.00	191.00	217.00	175.00
Si1	144.00	140.00	136.00	136.00	148.00	136.00	140.00	168.00	180.00
Qz	-7.00	-2.00	-4.00	-9.00	-6.00	-8.00	51.00	49.00	-5.00
T1	0.75	1.09	0.73	1.32	1.08	1.14	1.13	1.45	1.08
CIPW	**VALUE**								
Q	1.50	2.40	0.78	2.28	3.66	2.94	10.50	18.96	14.36
Or	20.02	13.34	13.90	2.24	11.12	7.23	23.04	30.02	20.02
Ab	18.34	21.48	18.86	29.87	28.30	27.77	20.44	15.2	18.86
An	13.34	17.24	16.12	8.06	5.00	4.17	8.34	5.28	11.12
Di	15.31	17.10	15.52	14.38	24.95	21.61	14.46	16.12	11.30
Mt	4.64	4.41	2.55	10.21	5.57	7.89	2.09	4.87	7.19
Hy	26.00	20.35	30.40	30.47	18.71	25.27	18.17	7.02	14.93
I1	0..76	1.06	–	1.37	1.06	1.22	0.91	1.06	0.76
Ap	–	2.27	1.86	0.93	1.86	1.86	1.86	0.93	1.86
ϕ	20.13	29.44	29.93	19.73	16.88	15.40	37.23	26.36	27.97

orthoclase. The K_2O content (average 2.05 wt. %) is low and this accounts for the low modal percentage and normative K-feldspar (Table 1 and 2)

Hornblende –biotite gneiss presents a different picture. The silica content here is 60.70 wt.% on the average and this is similar to the average composition of biotite –hornblende gneiss of Oban massif (Ekwueme 1990). CaO and K_2O on the average are respectively 5.60 and 3.27 wt.%. Also these values are not too different from the values for Oban gneisses (Ekwueme op. cit.) The average Al_2O_3 content is 10.49 and 11.03 wt.% for pyroxene gneisses and hornblende-biotite gneiss respectively (Table 2). The Niggli al < alk+c as observed from Table 2 and the absence of sillimanite in the pyroxene gneisses supports this Niggli relationship. Similarly, the average alk < al is consistent with the absence of argerine since excess alkalis would have aided its formation (Leake and Singh, 1986)

The quartz index (qz) in both the pyroxene gneisses and the hornblende – biotite gneiss shows a marked difference. The values are higher in hornblende –biotite gneiss reflecting greater modal quartz in the hornblende-biotite gneiss than in pyroxene gneiss.

Generally, Si is less than 500 and is consistent with the high MgO percentage in pyroxene gneisses. The pyroxene gneisses composition is more basic than that of the hornblende – biotite gneisses. This is a common feature of granulites.

METAMORPHISM:

The Nigerian Basement complex has undergone polyphase deformation and polymetamorphism during the Proterozoic and early Phanerozoic periods (Onyeagocha and Ekwueme 1990). The field relations, contact effects and petrographic details of the rocks of the Obudu Plateau highlight the rocks as being of magmatic origin and having experienced high grade metamorphism (Orajaka 1971) The mineralogy and geochemistry of the rocks of the area confirm this.

The pyroxene gneisses in the study area exhibit the following assemblages.

(i) Plag. +Opx + Cpx + Qz+ Mt (ii) Plag + Opx +Cpx + Qz + Mt + Hb

(iii) Plag. + Opx + Cpx + Qz + Mt + Hb + Bi

The first two assemblages (i) and (ii) represent the orthopyroxene granulite facies (De Waard 1965) and the intermediate pressure granulites of Green and Ringwood (1967). Assemblage (iii) is the hornblende granulite facies. The typical assemblage is:

Plag + Opx + Cpx ± Qz± Hb with accessories such as magnetite, ilmenite, spinel, apatite, zircon and biotite.

The presence of clinopyroxene, relative low proportion of quartz occurring along with spinel; the absence of biotite are indicative of the pyroxene gneisses varieties (i) and (ii) being high temperature pyroxene gneisses. The occurrence of spinel + quartz indicates very high temperature granulites (Lal et. al 1987; Kamineni and Rao 1988). The complete absence of cordierite indicates that metamorphism was medium pressure variety (Miyashiro, 1993; Newton, 1983). The coexistence of orthopyroxene and clinopyroxene in the presence of quartz and plagioclase gives assemblage characteristic of the granulite facies (Miyashiro 1994).

The antiperthitic texture, poorly defined foliation, myrmekitic intergrowth of quartz symplectites lend credence to high–grade metamorphism in the area. The rocks generally have granular texture and occasional triple point confirm stable co-existence of these minerals (Fig. 5). Ekwueme (1990) has earlier reported on the occurrence of pyroxene as one of the essential members of the mineral assemblage in the relicts and also in the garnet- hornblende gneisses in the adjoining Obudu cattle ranch area.

The polymetamorphic nature of the rocks of the Obudu Plateau in which one of the episodes is up to granulite facies has been reported by Ekwueme (1994). The local occurrence of minerals such as second generation biotite, chlorite and uralite (rims) is indicative of partial retrogressive metamorphic effects. Similarly, Orthopyroxene with reaction rims of cummingtonite also supports retrogressive metamorphism (hydration only).

The map area is a polymetamorphic terrain and metamorphism attained the granulite facies over a considerable area. The transition from amphibolite to granulite facies is a result of the following reactions of De Waard (1965):

a) $Na_2Ca_2(Fe, Mg)_4 Al_3Si_6O_{22}(OH) + 4SiO_4 \leftrightarrow 3(Fe, Mg)SiO_3 + Ca(Fe, Mg)Si_2O_6 + NaAlSi_3O_8 + CaAl2Si_3O_8 + H_2O$

hornblende — quartz — orthpyroxene — clincpyrexene — Plagioclase

b) $Na_2Ca_2(Fe, Mg)_4 Al_3Si_6O_{22}(OH) + 2K_2(Fe, Mg)_{5½} Al_3SiO_{20}(OH) + 17SiO2 \leftrightarrow 15(Fe.Mg)SiO_3 + 4 KAlSi_3O_8 + NaAlSi_3O_8 + CaAl_2Si_3O_8 + 5 H_2O$

hornblende — biotite — quartz — orthopyroxene — orthoclase — plagioclase

Such complex reactions could have resulted in the disappearance of hornblende in rocks with assemblage (i) and biotite from rocks with assemblage (ii). The presence of hornblende in most of the rocks means the environment was not completely anhydrous.

CONCLUSION

The rocks of the Ukwortung area of the Obudu Plateau have experienced polycyclic metamorphism. The occurrence of hypersthene and clinopyroxene together with spinel along with quartz is characteristic of the granulite facies. The granular textures exhibited by most of the gneisses *further confirms* that gneisses of Ukwortung area underwent granulite facies metamorphism on a wide scale. This was followed by subsequent lower grade *retrogressive* stages during the uplift of the complex.

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REFERENCES

Clifford, T. N., 1970. The structural framework of Africa. In T. N. Clifford and I. G. Gass (eds). African magnetism and tectonics. Oliver and Boyd. London p 1- 26

De Waard. D., 1965. The occurrence of garnet in the granulite –facies terrain of the Adirondack High lands. Jour. Petrol. 6: 165 – 191

Deer. W. A., Howie. R. A. and Zussman. J., 1966. An introduction to the Rock- forming Minerals. Longman, London. 528p

Ekwueme. B. N., 1987. Structural Orientations and Precambrian deformational episodes of Uwet area. Oban massif. S. E. Nigeria. Precambrian Res., 34: 269 – 289.

Ekwueme. B. N., 1990. Petrology of southern Obudu Plateau. Bamenda Massif Southeastern Nigeria. In : Rocci. G. and Deschamps. M (Coordinators). Recent Data in African Earth Sciences. CIFEG Occassional Publ. 1990/92: 155 –158.

Ekwueme, B. N., 1994. Basaltic magmatism related to the early stage of rifting along the Benue Trough: The Obudu dolerites of South-eastern Nigeria. Geol. Jour. 29: 269 – 276

Ekwueme, B. N., and Onyeagocha. A. C., 1985. Petrology of Intrusive rocks in the basement complex of Uwet area, Oban massif south-eastern Nigeria. Nig. Jour. Min. Geol., 22: 71-78

Green, D. H. and Ringwood. A. E., 1967. An experimental investigation of gabbro to eclogite transformation and its petrological applications. Geochim. Et Cosmochim. Acta 31: 767 –833

Kamineni, D. C. and Roa, A. T., 1988. Sapphirine granulites from the Kakanuru area. Eastern Ghats. India: Am. Mineral., 73: 692-700

Kennedy, W. Q.,1964. The structural differentiation of Africa in Pan African (±550my). Tectonic episode.Res. Inst. African Geol. Univ. Leeds 8th Ann. Rept. P 48.

Lal, R. K., Ackermend. D. and Upadhay. H., 1987. P- T –X relationships deduced from corona textures in sapphirine – Spinel –quartz assemblages from Paderu. Southern India. Jour. Petrol., 28: 1139 – 1168.

Leake, B. E. and Singh, O., 1986. The Delany Dome Formation. Connemarra. W. Ireland. and the geochemical distinction of ortho-and para quartzo-feldspathic rocks. Mineral. Mag., 50: 205 – 215.

McCurry, P., 1976. The Geology of the Precambrian to Lower Palaeozoic rocks of Northern Nigeria – A review. In: C. A. Kogbe (ed.). Geology of Nigeria. Elizabethan Publ. Co., Lagos. Nigeria. P. 15 – 39.

Miyashiro, A., 1973. Metamorphism and Metamorphic Belts. George Allen and Unwin. London 422p.

Miyashiro, A., 1994. Metamorphic Petrology. UCL Press Ltd. London. 404p. Newton. R. C. 1983. Geobarometry of high grade metamorphic rocks. Amer. J. Sci 283-A, 1 – 28.

Onyeagocha. A. C. 1979. Basement rocks of the Akwanga. N. W (Sheet 209). Plateau State. Nigeria. J. Min. Geol., 8(15, 16): 96- 97.

Onyeagocha. A. C. and Ekwueme. B. N., 1990. Temperature–Pressure distribution patterns. in metamorphosed rocks of the Nigerian basement complex. a preliminary analysis. Jour. Afr. Earth Sci. 11: 83 – 93.

Orajaka. S. 1971. The petrogenesis of the Obudu-type enderbite. J. Mines, Metals and Fuels (Calcutta), p. 94 – 98.

Oyawoye, M. O., 1972. The geology of the Nigerian basement complex. A survey of our present knowledge of them. Nig. Min. Geol. Metall. Soc. 1: 87-103.

Rahaman, M. A., 1976. Review of basement geology of southwestern Nigeria. In: C. A. Kogbe (ed.) Geology of Nigeria. Elizabethan Publ., Lagos. Nigeria. P.41-57.

Turner, D. C. 1993. Upper Proterozoic Schist belts in the Nigerian sector of the Pan African Province of West Africa. Precambrian Res., 21: 55-79.