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PETROLOGY, GEOCHEMISTRY AND Rb-Sr
GEOCHRONOLOGY OF METAMORPHOSED
ROCKS OF UWET AREA SOUTHEASTERN NIGERIA

BY

PP 176

BARTHOLOMEW NWOYE EKWUEME

(B.Sc. HONS., M.PHIL.)

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D E D I C A T I O N

This thesis is dedicated:

(i) With love:

to Olunwa and Nena
(my wife and daughter)
for their love and companionship;

(ii) With gratitude:

to A. C. Onyeagocha
(my most inspiring teacher)
for my academic attainment;

(iii) With honour:

to Maria Omuh
(my late grandmother)
for her great care and love for me.

A B S T R A C T

Field, petrographic, geochemical and isotopic studies on Uwet Area of Southeastern Nigeria indicate that polyphase deformation and polymetamorphism have transformed pelites, semi-pelites, calcareous pelites, greywackes and basic to intermediate igneous rocks into phyllites, schists, amphibolites, gneisses and migmatites.

Mesoscopic and microscopic structures indicate at least three deformational episodes which can be distinguished in the field by structural trends in the N-S to NE-SW ($0-40^{\circ}$ azimuth); ENE-WSW ($50^{\circ}-70^{\circ}$ azimuth) and NW-SE ($100^{\circ}-140^{\circ}$ azimuth). Thin section study indicates discordant Si-Se trails associated with mineral porphyroblasts, multiple foliations and retrograde minerals cutting the main fabric of high-grade rocks.

Rb/Sr whole-rock analyses give ages of 922 ± 20 Ma for migmatitic gneiss; 784 ± 31 Ma for banded amphibolite; 676 ± 26 Ma for phyllite, gneisses and some schists; and Ca. 527 ± 16 Ma for the migmatitic schists. The last two ages fall within the Pan African thermotectonic event dated as 600 ± 150 Ma.

Regional dynamothermal metamorphism of the kyanite-sillimanite type has been recognized in the Uwet area. Metamorphic isograds, based on the entry of pelitic index minerals, biotite, garnet, kyanite and sillimanite have been

napped. The distribution of these isograds indicates a northwest to southeast increase in the intensity of metamorphism from medium greenschist facies to uppermost amphibolite facies. The mineralogical assemblage (quartz-plagioclase-biotite-green hornblende-epidote) in the homogenous amphibolite indicates that it attained at least lower amphibolite facies metamorphism whereas the banding, association with migmatite and the abundance of brown hornblende coupled with the absence of stable epidote in the banded amphibolite indicate that it attained an upper amphibolite facies regional metamorphism.

Magmatism of calc-alkaline and tholeiitic basic types resulted in the intrusion of granite, granodiorite, tonalite and dolerite in the Uwet area. The calc-alkaline magmatism triggered off K-metasomatism which caused extensive microclinisation of these rocks.

Sedimentary rocks (shale, limestone and sandstone) belonging to the Asu River Group, the Eze-Aku Formation, the Nkporo Shale and the Benin Formation were deposited unconformably on the basement rocks between the Cretaceous and Tertiary times.

A C K N O W L E D G E M E N T S

The inspiration for this study came from Dr. A. C. Onyeagocha. Not only did he suggest this project, he also encouraged and guided me through rigorous field-checking exercises and careful but blunt criticism of the various drafts of this thesis. My greatest gratitude goes to him.

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CHAPTER ONE

I N T R O D U C T I O N

1.1 GEOLOGICAL SETTING

The Nigerian topographic sheet 323 (Uwet) is located in the geologically unexplored Oban Massif of Nigeria. The massif which is in the boundary of Cross River State of Nigeria and Cameroon Republic is approximately 100,000 square kilometers. The area of investigation is the degree sheet 323 (Uwet) which lies between longitudes $8^{\circ}00'E$ and $8^{\circ}30'E$ and latitudes $5^{\circ}00'N$ and $5^{\circ}30'N$ (Fig. 1).

Uwet sheet is a part of the Eastern Nigeria highlands. These highlands consist of two giant spurs which are the western prolongation of the Cameroon Mountains into the Cross River plains. These spurs are known as the Obudu Plateau and the Oban Hills. The area of investigation is an extension of the Oban Hills. The Oban Hills consist of a deeply dissected plateau which in places attain a height of 1,125m above mean sea level (Ofomota 1975). The area therefore has an undulating topography. This topography gradually rises towards Benue State in the north and towards the foot hills of the Cameroon Mountains in the East. The eastern elevation is about 137m above sea-level but generally appears as a plain. The area becomes hilly as one moves towards the western part.

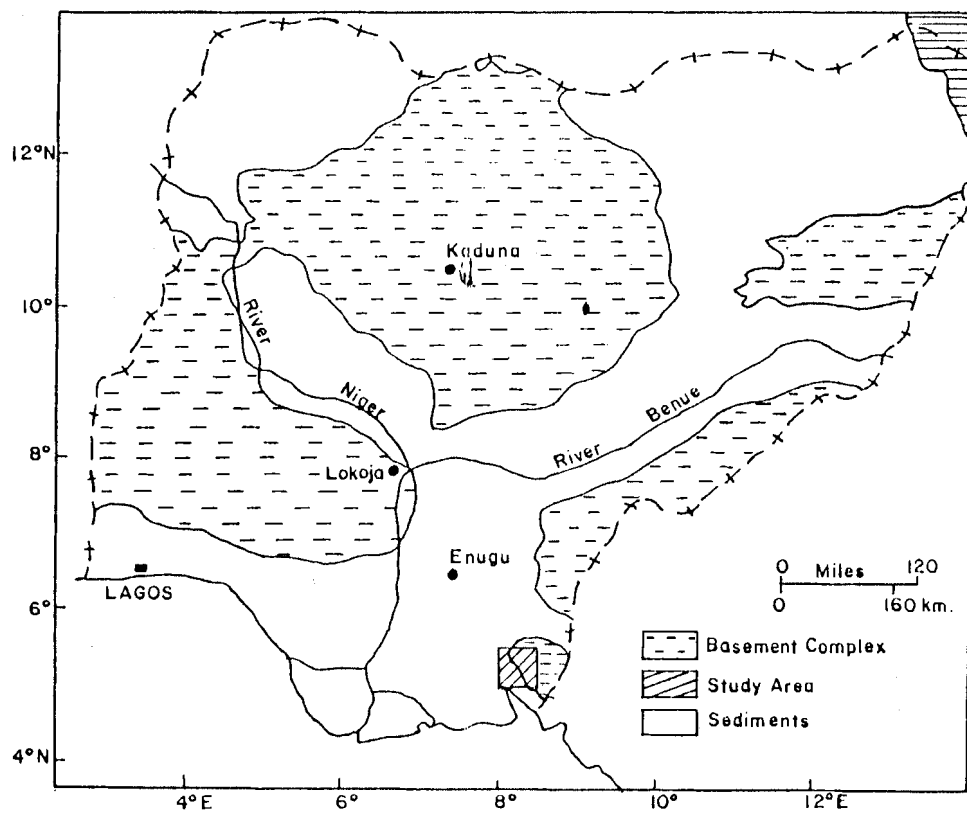


FIG.1 Location of Study Area on the Geological map of Nigeria.

On this western side, the highest elevation is about 183m above sea-level. These hills are made up, dominantly, of schists whereas the eastern part consists mainly of gneisses, pegmatitic granites and granodiorites. The extreme south which is basically a low land is characterized by shale, sandstone and limestone lying unconformably on the basement rock.

The Cross River, the Great Kwa River, the Calabar River and the Inyang Ita River drain the map area. Their flow appears to be structurally controlled since they flow from north to south which is the trend of major structural features (for example, foliations, fold axes and major joints) in the area. Most of these rivers are reduced in volume during the dry season thereby exposing fresh rock samples. Most of the rocks in the area are intensely weathered. The rocks most susceptible to weathering are the highly micaceous schists that cover most of the western portion. These schists weather into clayey soils with a reddish colour. Weathered pegmatites and granites are often indicated by scattered flakes of shiny muscovite on the surface.

The study area is in part ~~rendered~~ impenetrable by the equatorial evergreen rainforest. The only major roads traversing the area are the Calabar - Ikom and the Calabar - Ekom roads. Others are secondary.

1.2 NATURE OF STUDY

The Oban Massif is a part of the Basement Complex of Nigeria. This complex consists mainly of schists, gneisses, migmatites, metasediments and intrusive rocks of granitic composition (McCurry 1976). The schists are thought to belong to the Newer Metasedimentary series which represent an in-folded sedimentary cover into the gneiss - migmatite - quartzite complex (Rahaman 1976). Oyawoye (1972) stated that schists and metasediments are confined to the western side of the country along a North-South trending trough. He went further to state that this contrasts with the disposition of younger volcanics and intrusives on the eastern parts. Metasediments, he said, "are virtually absent on the eastern side of the country".

Grant (1971) has assigned a Pan-African age of 600 ± 150 Ma to the slightly migmatized to non-migmatized paraschists and a minimum Eburnean age ($2,000 \pm 200$ Ma) and more likely Liberian age ($2,800 \pm 200$ Ma) to the gneiss-migmatite - quartzite complex of the Ibadan area. At least two episodes of deformation affected the complex and might have occurred prior to or contemporaneous with the metamorphic events (Oyawoye 1964; McCurry 1976; Rahaman 1976; Onyeagocha 1984). The latest episode of these deformations is believed to be Pan-African in age (600 ± 150 Ma).

The purpose of this investigation is to map the Uwet area in detail and to study the mineralogical and chemical composition of the rocks. This will make it possible to:

- (i) differentiate the hitherto undifferentiated basement rocks,
- (ii) locate metamorphic isograds and zones,
- (iii) interpret the temperature, pressure, degree and timing of the metamorphism of the area,
- (iv) ascertain the nature and peculiarities of the parent rocks and
- (v) evaluate the stratigraphy of the area through the geochronological studies of the rocks.

Field work consisted of collection of representative samples of each lithologic unit mapped and the recognition of the contact relationship between them. Many of the samples were collected at quarry sites which are scattered all over the area. River beds and channels expose fresh rock samples in the dry season.

Representative samples were studied using the petrological microscope. The bulk rock compositions of the rocks were obtained using X-ray fluorescence and atomic absorption spectrometers. Mass spectrometers were used to determine the Rb and Sr contents of the rocks for geochronological study.

CHAPTER TWOGENERAL GEOLOGY2.1 PHYLLITES

Phyllites crop out in Camp 1 of the Calaro Estate. These phyllites are light-coloured and consist dominantly of muscovite, chlorite and biotite. They are highly weathered. They are folded parallel to their foliations which varies from $N20^{\circ}E$ to $N30^{\circ}E$. The foliations dip $8^{\circ}NW$.

A dark coloured, fine-grained phyllite with a characteristic sheen covers the whole stream channel about one kilometer north of Camp 5 of the Calaro Estate. It is weakly foliated and composed dominantly of biotite and chlorite. The general trend of the outcrop is northwest. Metaquartzitic selvages are present in the phyllite possibly indicating a sandstone-shale sequence of the original (i.e. pre-metamorphic) sedimentary rock.

2.2 SCHISTS

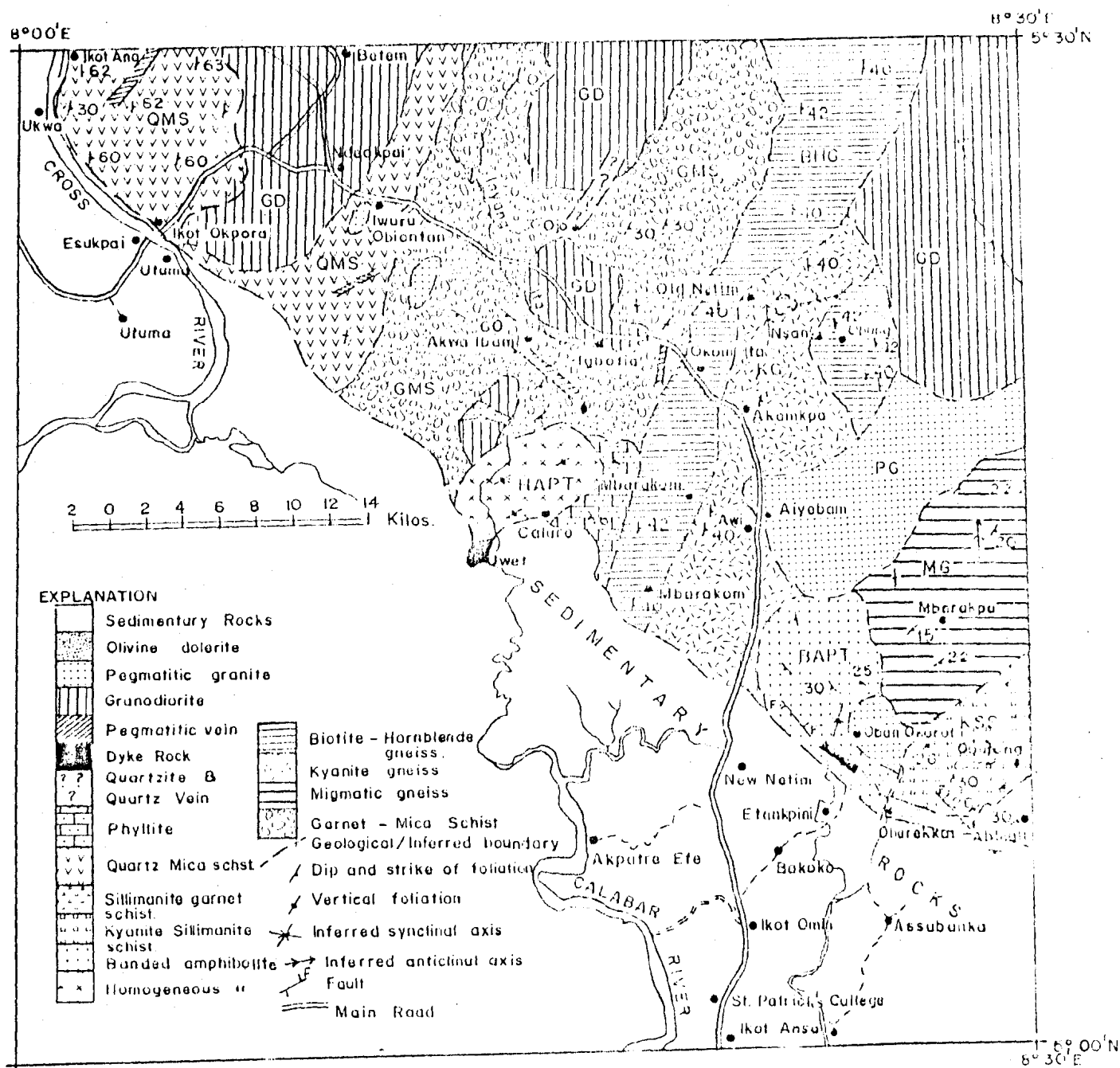
Schists are restricted in their occurrence. Most outcrops occur in the northwest quadrant of the degree sheet. However, schists occupy the channels of the Great Kwa River and also occur around Abbiati in the southeastern portion of the sheet. Megascopically, the schists can be grouped into three on the basis of texture:

- (i) fine-grained schists
- (ii) medium-grained schists
- (iii) coarse-grained schists.

The fine-grained schists crop out in Ikot Okpora where they are overlain by sandstone beds. They also cover the whole of Ikot Ana in the northwest and extend to the Cross River Channel. The fine-grained schists are a little coarser than the phyllites and some of the minerals, for example, biotite, muscovite and quartz are recognizable in hand specimen. The schists are intensely weathered and in some places (for example, Ikot Ana) the bedding planes of the original sedimentary sequence are still preserved. They are all foliated and jointed. Schistosity trend is N-S and the dip of the schistosity decreases from a maximum of 63°W to 30°W towards the Cross River Channel. The major joints are generally parallel to the schistosity but they are occasionally cut by minor joints trending east.

At Ikot Okpora, the fine-grained schists are intruded by granodiorites with which they have sharp contact relationships. The contact of the fine-grained schists with unmetamorphosed sediments (limestone, shale and sandstone) in the northwest is not exposed.

The medium-grained schist underlies the whole of Iwuru Obionthan (Figure 2) from where it extends to the Dunlop Rubber Estate. Outcrops of this schist occur also in Igbofia, Akwa Ibiam and Ojo (Figure 2). Characteristic of the medium-grained schists are porphyroblasts of garnet



and flakes of muscovite and biotite which are recognizable megascopically. They also contain quartzo-feldspathic veins which mostly run parallel to and occasionally cut across the schistosity. Some of these veins are contorted and folded. The schist is intensely deformed. It shows variable schistosity trends. For example, in Igbofia, the trend of the schistosity defined mostly by biotite is NNE-SSW which is more or less N-S. Here, the quartzo-feldspathic veins define a second set of foliation in the NW-SE direction. At Akwa Ibiami, the schistosity trends N40°W and dips 60°NE. Here, the schist is intensely weathered. At Ojo, the medium-grained schist outcrops in stream channels. It contains garnet, hornblende and secondary calcite.

A common feature of most of the medium-grained schist is its extensive invasion by intrusive granodioritic rocks as compared to other rock types in the area. However, pegmatite bodies and veins occur as well. In most of the granitoid rocks for example, UW1, the medium-grained schist occurs as xenoliths (Figure 3). These xenoliths display schistosity and occur as darker patches in the granitoid rock. They are dominantly composed of biotite and could have resulted from magmatic stoping which possibly emplaced the granitoid rock in the area.



Figure 3 Schist xenolith in granitoid rock.

The coarse-grained schist crops out at the Kwa Falls and Abbiati in the southeastern part of the map area (Figure 2). Conspicuous segregation into light and dark portions are characteristic of the coarse-grained schist. At the Kwa Falls, the light portion of the schist contains porphyroblasts of kyanite and sillimanite. They are less schistose than the dark portion. On the other hand, the dark portion of the schist is highly foliated and consists of mafic minerals dominantly the phyllosilicates. Effervescence was observed on application of hydrochloric acid to the dark portion of the schist. No effervescence was however, observed when the same acid was applied to the light portion of the schist. This indicates the calcareous nature (possibly due to secondary calcite) of the schist at the Kwa Falls. The coarse-grained schist is associated with boulders of pegmatitic granite at the Kwa Falls. The schist is intensely deformed. Schistosity trends $N40^{\circ}E$ to $N50^{\circ}E$ with dips varying from 26° to $30^{\circ}NW$. Folds, boudins and faults were recognized in the schist at Kwa Falls.

At Abbiati, conspicuous outcrops of the coarse-grained schist occur. Here the schist has a sharp contact relationship with the Mfamosing Limestone which is Albian in age. The schist here exhibits crude banding into leucocratic parts which are richer in quartz and feldspar and melanocratic portions

which are richer in biotite and garnet. Possible recrystallization at high temperatures resulted in abundant K-feldspar crystals which are enclosed as large aggregate crystals in the schist. The schist has been intensely deformed. Schistosity trend is $N30^{\circ}E$ and dip is $26^{\circ}NW$. Folds, truncation and foliation offsets are observed in the coarse-grained schist at Abbiati.

2.3 AMPHIBOLITES

Two types of amphibolites occur in Uwet area:

- (i) banded and ,
- (ii) homogenous amphibolites.

A thinly banded amphibolite has a sharp contact relationship with the sandstone of Awi Formation in the central portion of the map area. The rock which is very dark in colour, is tough and varies in texture from medium- to coarse-grained. The foliation trend is generally NW-SE (about 140° Azimuth) with a dip varying from 20° to $30^{\circ}NE$. This is contrary to the predominantly N-S Pan-African trend but has been reported in the Akwanga area of north-central Nigeria where regional foliation trending NE-SW was observed to offset another trending NW-SE (Onyeagocha and Ekwueme 1982). Isoclinal folds with axes trending 250° Azimuth, boudin structures and undeformed mafic dykes (trending 146°) were recognized in the banded amphibolite. The foliation is

parallel to the layering in the parallel - folded rocks and this indicates that the foliation is older than the folds.

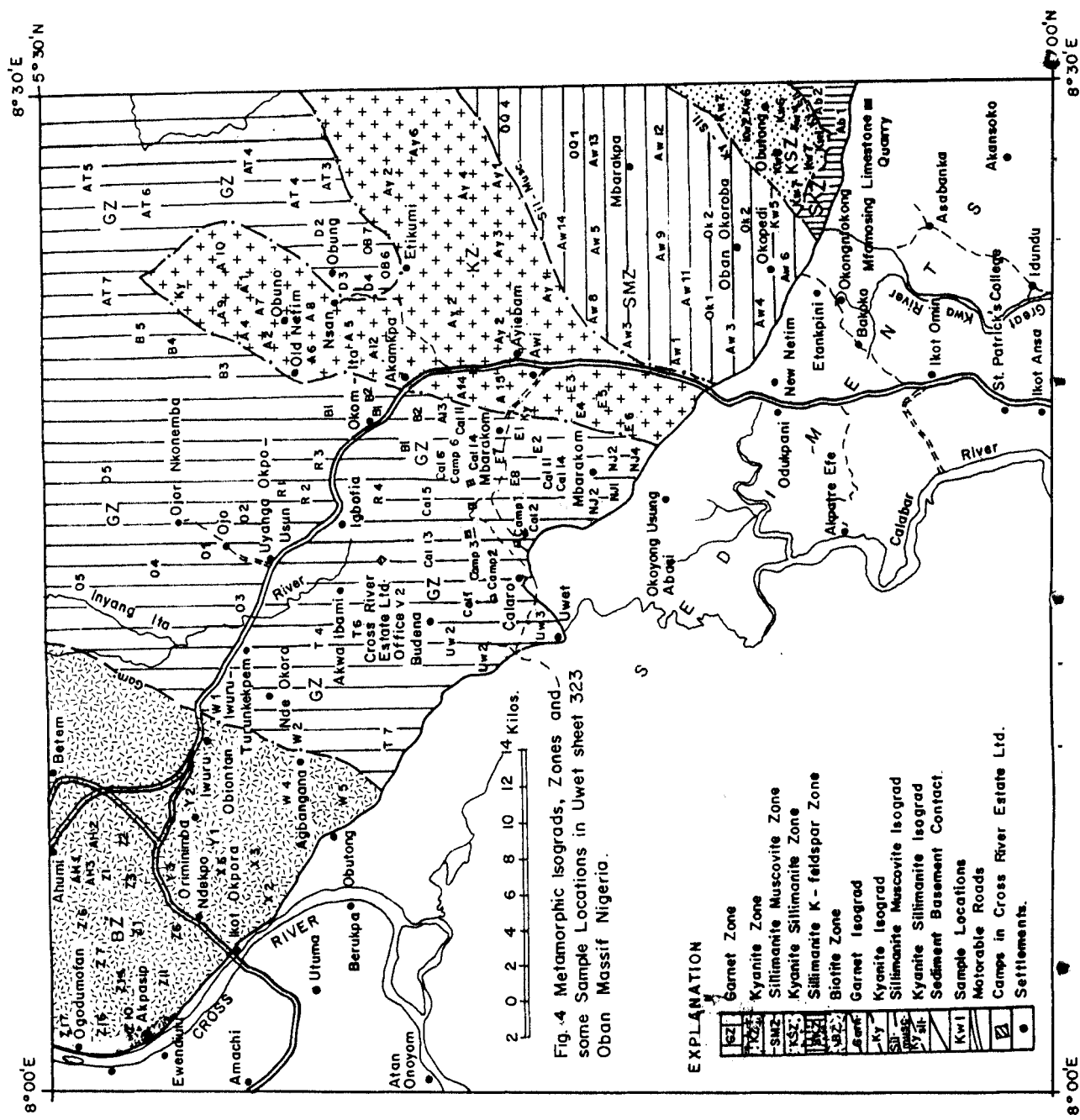
A homogenous amphibolite covers the channels of the Calabar River and Inyang Ita River at the Calaro Estate. Sample Cal I (Figure 4) was collected at the bank of the Calabar River southwest of Camp 6 in the estate. The amphibolite is dark, foliated and medium-grained. The foliation trend is $N20^{\circ}E$ and the dip is nearly vertical. In hand specimen, porphyroblasts of hornblende which make up more than 70 per cent of the rock are easily recognized. Unlike most of the schist outcrops, the amphibolite is relatively fresh and shows little or no effect of weathering activity.

2.4 QUARTZO-FELDSPATHIC GNEISSES

The eastern (northeast and southeast) portion of the map area is underlain by quartzo-feldspathic gneiss (Figure 2). Two major types of quartzo-feldspathic gneiss can be distinguished in the area:

- (i) biotite-hornblende gneiss
- (ii) Kyanite gneiss.

The biotite-hornblende gneiss outcrops at Okom Ita, Obung and the Calaro Estate. It is coarse-grained and strongly foliated in the N-S direction. The rock exhibits variable colour owing to differing concentration of biotite, hornblende and feldspars. Textural variation in the gneiss is due to the



changes in size and amount of K-feldspar. The K-feldspar forms porphyroblasts which attain a size up to 2cm across and is in places wrapped by biotite crystals. The porphyroblasts form augen structures in the gneiss.

The biotite-hornblende gneiss contains abundant biotite and hornblende-rich mafic xenoliths. At Okom Ita and Obung quarry, the gneiss is invaded by pegmatitic veins (for example, outcrop D6 Figure 4) which transect the N-S foliation trend of the rock in a perpendicular direction. Rehealed fractures are also associated with this gneiss. In-filling of the fractures (for example, OB7, Figure 4) are schistose materials dominantly composed of chlorite and biotite. Both the pegmatitic veins and the rehealed fractures could be products of recrystallization and subsequent segregation of the minerals in the host gneiss. Deposition of such materials is facilitated by volatile transport (Walther and Orville, 1982).

Generally, the biotite-hornblende gneiss is coarse-grained. It exhibits variations in both the trend and dip of the foliation. For example, in the Lavori Quarry at Obung the trend is essentially N-S with a dip of $42 \pm 2^\circ$ E whereas in Calaro Estate, it exhibits two sets of foliation trends. The first set which is conspicuous has a dominant NE-SW trend with an attitude of about 20° Azimuth. The second set truncates the first and

shows a trend in NNW-SSE direction with an attitude of 350° Azimuth. In the Calaro Estate of Uwet area, the angle between these two sets of foliation is observed to be about 30° . If the two sets represent two different events separated in time, then, the NW-SE trending foliation which is considered as primary is believed to be of a pre-Pan-African age whereas the NE-SW trending foliation is Pan-African (cf. Onyeagocha and Ekwueme 1982). Portions of the biotite-hornblende gneiss have undergone spheroidal weathering. Some outcrops appear to enclose pegmatitic granite bodies.

Outcrops of the kyanite gneiss are abundant at the Crush Rock Industry Quarry in Old Netim. It extends down southwards to Mbarakom and Awi (Figure 2). The rock is coarse-grained. The gneissosity which trends N-S and dips 42° E is in places deflected by large feldspar porphyroblasts which attain a size of 2cm x 3cm. The rock has been folded parallel to its gneissosity at Old Netim. Also the kyanite gneiss shows normal faulting here in the E-W direction and this trend of the fault is consistent with its occurrence in a period of relaxation following the main N-S deformation which affected the area. In the Old Netim Quarry, the kyanite gneiss is fractured and baked at its contact with a dolerite dyke which intrudes it (Figure 5). It shows fracture-fillings (for example, A7



Figure 5 Contact of dolerite dyke (dark) and
 kyanite gneiss (light).

Figure 4) similar to those of the biotite-hornblende gneiss. Pre-tectonic pegmatites, aplites, and quartz veins are common in the kyanite gneiss (Figures 6 and 7). Some of these outcrops of gneiss have been folded parallel to the gneissosity of the host rock (Figure 8).

2.5 MIGMATITES

The migmatite in the area assumes a lit-par-lit aspect at Mbarakpa, Oban Okoroba and Oban. The largest outcrops of banded gneiss were encountered at the Nigerian Mining Corporation Quarry at Oban (3km east of map area). Here the rock is coarse-grained and highly foliated. It is also isoclinally folded and displays axial plane foliation. The fold axes trend N-S and they are parallel to the foliation. There is an evidence of shear in this area as shown by the smooth chloritic surface that separates individual layers of the migmatite. The lit-par-lit gneiss is closely associated with pegmatitic granite. At the contact of the kyanite gneiss and the migmatite the bands are not as conspicuously developed as in the Oban quarry (for example, sample AW12 from Oban Okoroba).

At Ayiebam and Awi the gneisses in the map area start to grade imperceptibly to migmatite. Outcrop AY 1 (Figure 4) is highly foliated and shows effects of metamorphic segregation.



Figure 6 Cross-cutting relation of aplite.

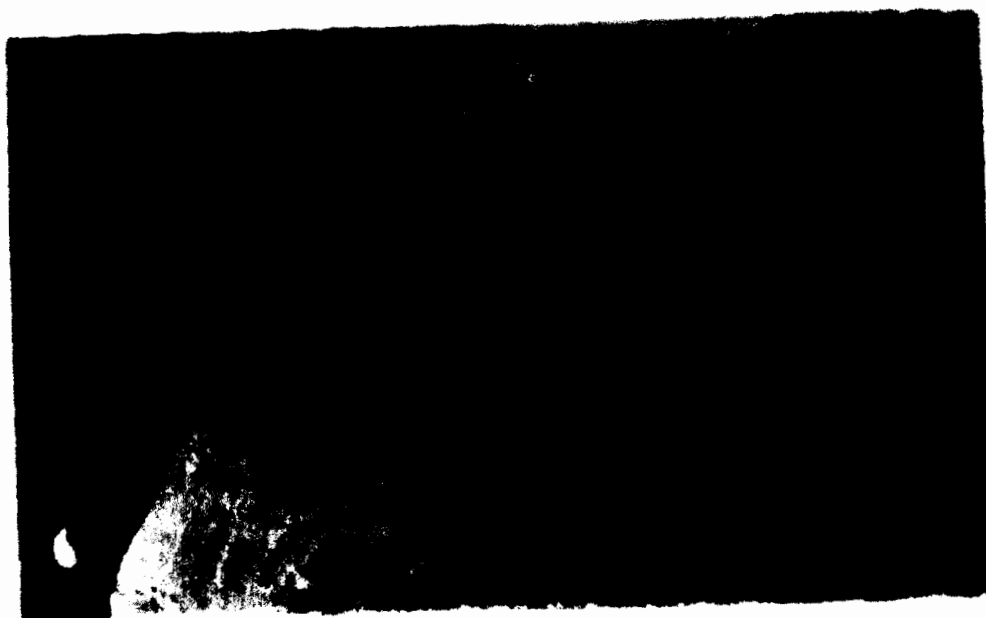


Figure 7 : Pegmatite veins in gneiss

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Figure 8 : Folding of a gneiss outcrop.

One section of the rock has a higher concentration of mafic minerals than the other indicating a trend towards incipient migmatization. In addition, the rock is associated with pegmatitic granite boulders (AY₂). Taken together, outcrops AY₁ and AY₂ (Figure 4) form agmatite type of migmatite. The rock is highly foliated in the N-S to N40°E direction. Major joints in the area trend N20°E whereas minor joints show a northwest trend.

2.6 DOLERITES:

A dolerite dyke intrudes the kyanite gneiss at the Old Netim quarry. It is dense, dark, medium grained, not deformed and unmetamorphosed. It exhibits spheroidal weathering and because of numerous joints in the outcrop, the top is weathered to form laterite. It displays chilled borders. Phenocrysts of olivine, pyroxene and labradorite are recognizable in hand specimen. Two types of joints were observed in the dolerite dyke ; tension joints were developed as a result of the cooling and shrinking of the intrusion differentially producing columnar and transverse joint sets. Compressional joints resulted from the tectonic (compressional) forces which acted on the area. These compressional joints trend N-S.

2.7 GRANITOID ROCKS:

The following granitoid rocks were mapped:

- (i) granodiorite
- (ii) meladiorite
- (iii) granite.

GRANODIORITE:

Granodiorite is the most widespread intrusive rock in the area. It outcrops mostly as isolated and in-situ boulders and shows typical ex-foliation weathering patterns. The granodiorite has a sharp contact with the enclosing rocks. Xenoliths of the country rocks, mostly schists, occur in the granodiorite.

Generally, the granodiorite is coarse to very coarse-grained in texture. Large pink prismatic phenocrysts of K-feldspar are abundant. Other minerals recognized in hand specimen are plagioclase, hornblende, biotite and quartz. The rock differs from granites in the area in having a lower percentage of silica and a higher calcium and magnesium content. The granodiorite is non-foliated and could have been emplaced post kinematically or at the dying stages of the Pan-African orogeny (600-150 m.a.). The granodiorite belongs to the Older Granite series recognized throughout Nigeria. A light-coloured dyke (AH₂) cuts the granodiorite at Ahumi (Figure 2).

MELADIORITE:

This does not occur as a mappable rock unit in the area but as a xenolith in granodiorite exposed at the Igbofia Rubber plantation. It is thought to be the oldest pluton in Uwet area and is now represented by a single large mass and its xenolith trains within the Uwet granodiorite (Figure 9).

The meladiorite is dark and fine-grained. Megascopically, plagioclase, hornblende, minor quartz and biotite are recognized in the rock. Meladiorite is commonly considered a hybrid rock (Truswell and Cope 1963). Direct evidence of the origin of the Igbofia meladiorite is not available. However, it might have been one of the earliest phases of Older Granite intrusions (Carter et al. 1963) since it occurs as xenoliths in the granodiorite. It is suggested that both the Igbofia meladiorite and the Uwet granodiorite seem to have been emplaced by a reactive stoping mechanism. This was presumably aided by high fluid contents which evolved in the late stages of crystallization as alkali-rich fluids (cf. Wyllie 1977) and localized as pegmatites, and K-feldspar phenocrysts.

GRANITE:

The granite in the area is pegmatitic. It is closely associated with gneisses and migmatites of the area. It occurs as scattered boulders and is generally coarse-grained.



Figure 9 : Meladiorite in granodiorite.
(The margin is basified).

Though non foliated, the granite bodies generally trend N-S which is the foliation plane and a plane of weakness of the country rock. Quartz, feldspar and muscovite are the dominant minerals in hand specimen. Tourmaline, beryl and garnet also occur in some outcrops.

2.8 SEDIMENTARY ROCKS:

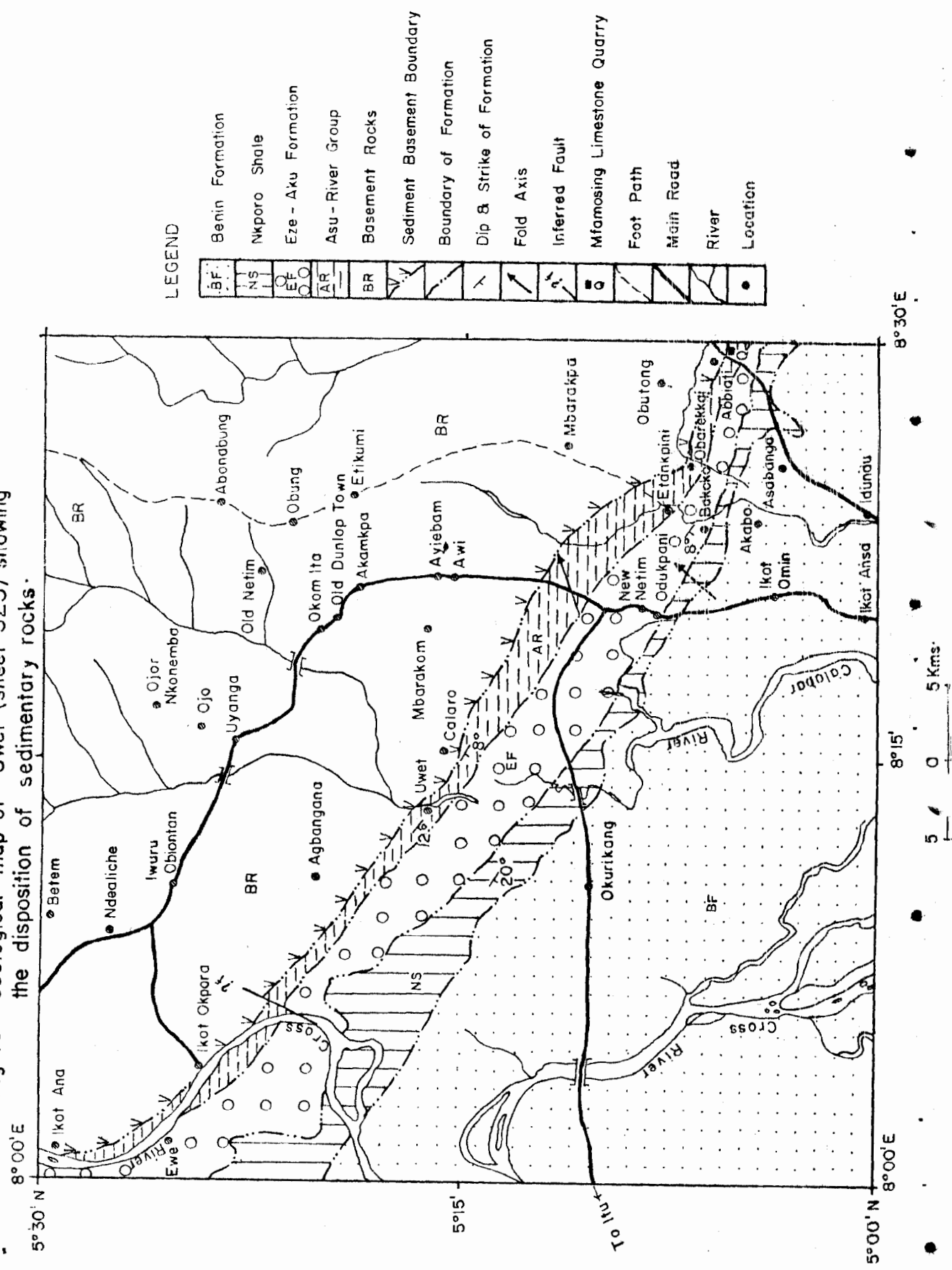
Overlying the basement rocks unconformably in Uwet area are sedimentary rocks of Cretaceous to Tertiary age. The sedimentary terrain consists of the Asu River Group, the Eze-Aku Formation, the Nkporo Shale Formation (Figure 10) all of Cretaceous age. The Nkporo shale is overlain by the Benin Formation (Figure 10) of late Tertiary-Quaternary age.

The Asu River Group (Reyment 1965) consists of

- (i) sandstone member
- (ii) shale member and
- (iii) limestone member.

These three members of the Asu River Group were recognized in Uwet area. They belong to the Odukpani Formation of Reyment (1965). The basal unit of the Odukpani Formation described as the Awi Formation (Adeleye and Fayose 1978) has a sharp contact with the basement rocks at Awi, Calaro Estate and Ikot Okpora (Figure 10). The Awi Formation comprising of fluviodeltaic sediments (dip is $8-14^{\circ}$ NE) is a folded sandstone, siltstone

Fig. 10 Geological map of Uwet (sheet 323) showing the disposition of sedimentary rocks.



and carbonaceous shale unit. Its contact with the basement rocks is marked by an unconformity represented by a conglomerate bed.

The Awi Formation is overlain by a sequence of limestones in Uwet area. The limestone which is thickly bedded in several locations is best exposed at the Cross River Limestone quarry at Mfamosing (Figure 10). The limestone exposed at the quarry is up to 50 meters in thickness. The limestone has a sharp contact with the basement rocks of Uwet area at Abbiati, Uwet and Ikot Okpora.

The Eze-Aku Formation consisting of limestone and calcareous shale is well exposed in Bakoko (Figure 10) and Okongtokong in the southeast of the map area. Here, it consists of highly fissile and gray to black shale. The dip of the shale is 8° NE and it strikes 160° azimuth. It is silty, calcareous and rich in pelecypod. Thick sections of yellowish marl (up to 30 meters thick) belonging to the Eze-Aku Formation outcrop in forests on both sides of the Calabar - Ekwang road (kilometers 101 and 102). These marls are highly fractured in the N-S and E-W directions. Some of the joints have widened into gorges.

The Nkporo shale marks the top of the Cretaceous succession in the map area. It is unconformable with the Eze-Aku Formation and consists of fissile, gray to black

shale which does not show effervescence on application of acid. This shows, that unlike its Odukpani and Eze-Aku counterparts, it is carbonaceous rather than calcareous. The Nkporo Shale exposures in the map area are discontinuous and can be observed in several road-cuts in the area. Above the marl band near Mmebu (kilometers 101 and 102 along the Calabar - Eking road) there is an exposure of Nkporo Shale. It is fissile and dips 20° NE. Between kilometers 36 and 43 along Calabar-Itu road, about 15 metres of blue - black fissile shale outcrops. There are thin beds of limestone and bands of gypsum. The top part of the shale contains Libycoceras and Inoceramus. It also contains fish bones and leaf impressions. The Nkporo Shale is Campanian - Maastrichtian in age.

The Benin Formation is the youngest rock unit in the study area. It is Tertiary in age and consists of highly ferruginous sandstone, occasional shale and thin bands of ironstone. In some locations, the sandstone is fine-grained while in others it is entirely conglomeritic. This unit is highly weathered and non-fossiliferous, although Ophiomorpha has been reported in it outside the map area (Onyeagocha 1980).

CHAPTER THREE

MINERALOGY AND PETROGRAPHY

3.1 METAMORPHIC ROCKS

About five hundred thin sections of rocks in Uwet area were studied using the petrological microscope. Tables 1, 2 and 3 show the modal compositions of the metamorphic rocks. Modal averages of minerals in rocks of Uwet area are presented in Table 4.

Quartz is ubiquitous in all the rocks. In all, quartz occurs in two sizes, as groundmass crystal in phyllite and schists and as porphyroblasts in gneisses. In the kyanite-sillimanite schist, secondary quartz is granoblastic and displays a 120° quartz-quartz triple junction structure (Figure 11). This indicates attainment of textural equilibrium in those parts of the schist (Spry 1969; Mason 1978). Some of the quartz in this schist are recrystallized as elongate and polygonised crystals strongly aligned parallel to the foliation of the rocks which is defined mainly by the phyllosilicates (Figure 11). Quartz is the commonest inclusion in other minerals, for example, garnet (Figure 12).

Plagioclase is abundant and together with quartz comprises 15 to 40 percent of the rocks. Most of the

TABLE 1 : MODAL CALCULATION OF MINERAL ABUNDANCES AND MINERALS IN GEDS SHEET

Minerals	Garnet-Kyanite schist		Garnet-Ilmenite schist		Garnet-Sillimanite schist		Kyanite-Sillimanite schist		Amphibolite (Homogeneous)					Pyroxite			
	R1	R2	D15	W1	W2	Ab1	Ab2	Im1	Im2	Im4	Im5	Im5	Ca11		Ca12	Ca13	Ca14
Quartz	30	25	35	13	18	20	20	10	20	10	10	10	12	12	13	12	10
Ilmenite	4	3	5	12	10	15	15	5	5	5	5	5	4	4	3	3	15
K-feldspar	-	-	-	-	-	15	15	-	-	3	-	-	-	-	-	-	-
Plagioclase	24	40	40	30	25	23	24	30	30	35	34	30	-	-	-	-	39
Muscovite	20	30	20	40	40	-	-	-	-	-	-	-	-	-	-	-	-
Garnet	-	-	-	3	5	14	15	5	-	3	5	5	-	-	-	-	2
Kyanite	-	-	-	-	-	-	-	5	20	35	5	5	-	-	-	-	-
Sillimanite	-	-	-	-	-	1	1	2	20	4	4	2	-	-	-	-	-
Chlorite	15	-	-	-	-	10	10	10	-	5	10	10	-	-	-	-	33
Orthopyroxene	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pyroxite	-	-	-	X	X	-	-	-	-	-	-	-	5	4	6	5	-
Hornblende	-	-	-	-	-	-	-	-	-	-	-	-	70	70	70	70	-
Sphene	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Calcite	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Zeolite	1	2	-	-	-	2	-	23	-	-	22	33	-	-	-	2	-
Crystals	-	-	-	-	-	-	-	-	-	-	-	-	1	1	2	5	-

X = PRESENT

TABLE 2 : MODAL COMPOSITION OF GNEISSES IN URBET SECT

MINERALS	Biotite-hornblende Gneiss										Kyanite Gneiss						
	D1	D6	B1	V2	Ga15	Ga18	Ga19	Ga111	Ga112	Ga114	Mc1	A4	A5	A8	B1	B2	AVI
Quartz	30	25	30	35	25	20	20	25	30	25	20	29	32	33	20	20	30
Plagioclase	24	20	22	23	20	15	15	5	6	4	21	25	20	30	22	22	25
Il-feldspar	6	10	16	3	3	10	5	5	5	5	5	21	14	5	4	3	4
Biotite	30	25	12	35	20	22	20	30	25	30	20	15	10	20	21	22	20
Muscovite	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-
Garnet	0.5	1	1	1	1	1	1	-	1	-	3	X	X	1	1	1	2
Kyanite	-	-	-	-	-	-	-	-	-	-	-	5	5	5	10	10	10
Chlorite	4	5	13	-	9	4	12	-	-	2	5	5	4	1	5	5	4
Epilote	-	6	-	-	3	3	3	-	10	5	2	-	-	4	2	2	2
Hornblende	5	5	2	2	10	25	23	22	20	25	14	-	-	-	12	13	-
Sphene	-	-	2	-	2	-	2	10	-	1	1	-	3	0.5	2	1	2
Calcite	-	-	-	-	6	-	-	-	1	-	-	-	-	-	-	-	-
Tourmaline	0.5	3	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-
Apatite	-	-	-	1	-	-	-	-	-	-	-	-	-	-	1	1	1
Sericite	-	-	-	-	-	-	-	-	-	-	-	-	-	0.5	-	-	-
Pyroxene	-	-	0.5	-	-	-	-	-	-	-	5	-	2	-	-	-	-
Opalines	-	-	1.5	-	-	-	-	-	-	-	2	-	1	-	-	-	-

TABLE 3 : MODAL COMPOSITION OF MIGMATITES AND BANDED AMPHIBOLITES

MINERALS	BANDED AMPHIBOLITE					MIGMATITE				
	AW3	AW5	AW6	AW16		AW8	AW11	AW12	AW12	AW15
Quartz	8	5	6	5		35	30	20	30	35
Plagioclase	10	10	2	8		12	12	15	8	15
K-Feldspar	-	-	-	-		10	17	35	18	25
Biotite	7	12	15	4.5		25	29	2	30	24
Muscovite	-	-	-	-		3	4	23	5	-
Carnet	-	-	-	-		-	2	2	2	-
Sillimanite	-	-	-	-		-	-	3	-	-
Chlorite	-	-	-	-		5	-	-	5	-
Epidote	-	-	-	-		-	-	-	-	-
Hornblende	75	73	72	72		-	6	-	-	-
Tourmaline	-	-	-	0.5		-	-	-	-	0.5
Zircon	-	-	-	-		-	-	-	-	-
Opques	-	-	3	-		-	-	-	0.5	-
Myrmekite	-	-	-	-		-	-	-	1.5	-

TABLE 4: MODAL AVERAGES OF MINERALS IN ROCKS OF THE ABEL, S. E. TERRACE

MINERALS	QzS	GrsS	Gss	Kss	Phy	EnF	BzG	Kg	Kg	EnF	Gz	Dcl
Quartz	30.0	15.0	20.0	17.0	10.0	12.25	26.0	26.8	30.0	6.0	21.0	-
Ilmenite	4.0	11.0	15.0	5.0	17.0	3.5	16.0	24.0	12.4	7.5	22.0	45.0
Ilmenite	-	-	15.0	1.6	-	-	7.0	9.7	21.0	-	11.3	-
Biotite	34.7	27.5	23.5	31.80	38.5	-	20.0	20.0	22.0	3.6	22.0	-
Muscovite	25.3	42.5	-	-	-	-	-	-	8.6	-	6.2	-
Garnet	-	4.0	14.5	3.6	2.0	-	1.0	0.6	1.3	-	-	-
Kyanite	-	-	1.0	14.60	-	-	-	7.0	-	-	-	-
Sillimanite	-	-	10.0	6.4	-	-	-	-	1.2	-	-	-
Chlorite	5.0	-	-	7.0	32.5	-	5.0	2.0	2.0	2.2	-	-
Epidote	-	-	-	-	-	5.0	3.0	1.6	-	-	2.3	-
Hornblende	-	-	-	-	-	70.0	17.0	5.0	1.2	77.8	0.6	-
Sphene	-	-	-	-	-	0.5	2.0	1.3	-	-	1.0	-
Calcite	-	-	-	17.6	-	0.75	1.0	-	-	-	-	-
Tourmaline	1.0	-	1.0	-	-	1.0	1.0	1.0	-	0.1	-	-
Opal	-	-	-	0.4	-	7.0	1.0	1.0	0.3	0.8	0.0	3.0
Clay	-	-	-	-	-	-	-	-	-	-	-	3.0
Pyroxene	-	-	-	-	-	-	-	-	-	-	-	44.0

QzS : Quartz
 GrsS : Garnet-sillimanite schist
 Gss : Garnet-sillimanite schist
 Kss : Kyanite-sillimanite schist
 Phy : Pyroxene
 EnF : Homogeneous amphibolite
 BzG : Biotite-garnet
 Kg : Kyanite
 Dcl : Diagenetic

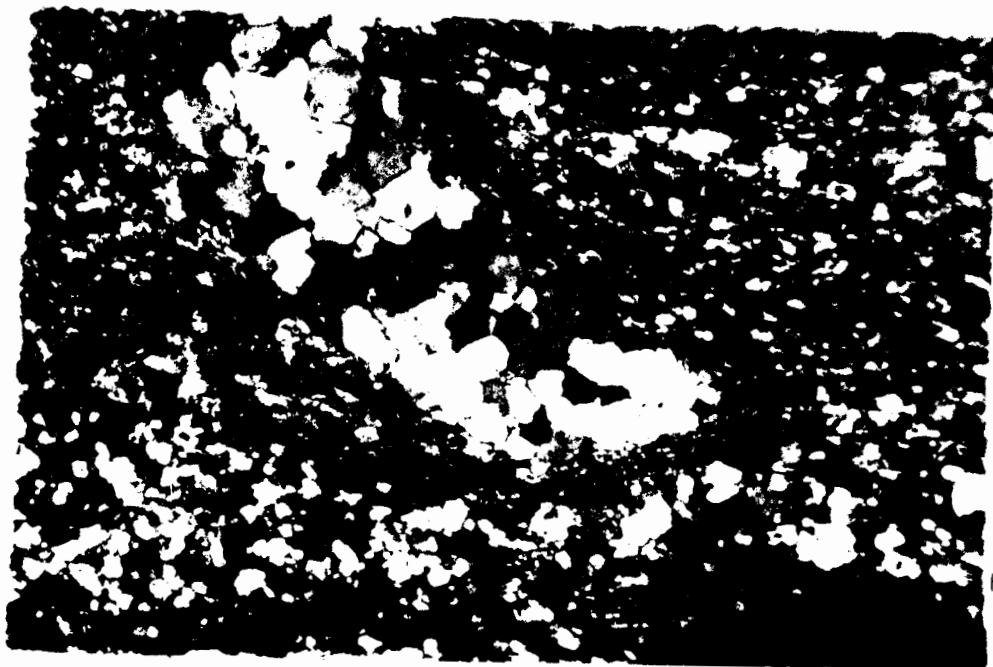


Figure 11 : Quartz forming 120° triple junctions
and enhancing the foliation of the
kyanite-sillimanite schist (XPL; X 10)

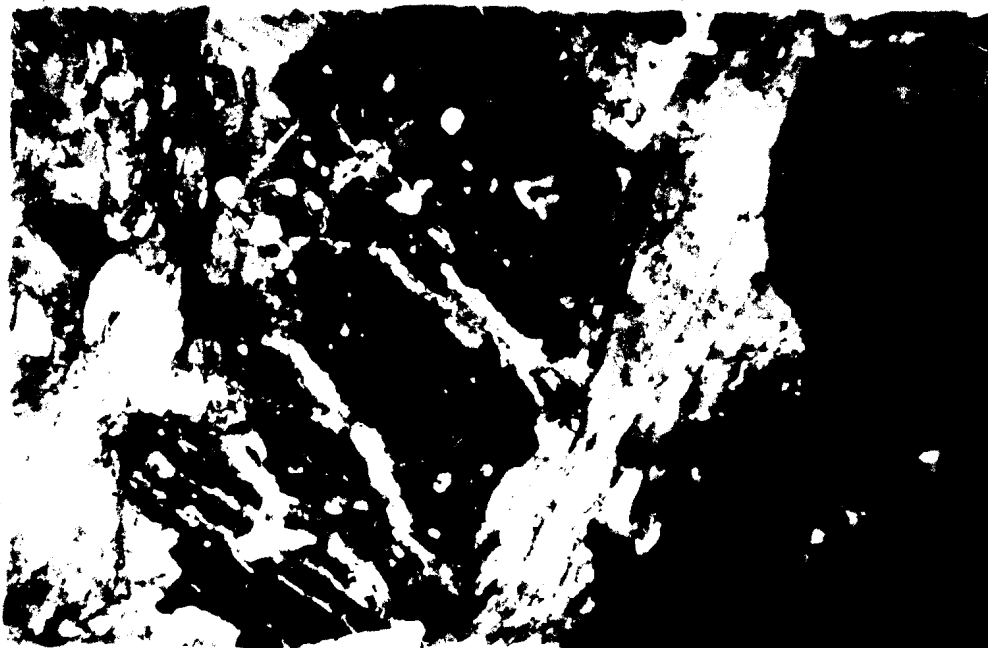


Figure 12 : Garnet riddled with inclusions of quartz and phyllosilicates in the garnet-sillimanite schist (XPL; X 10)

plagioclase occurs as clear elongate to granoblastic crystals. Zoning is rare in the plagioclase due to homogenization at higher temperature (Tracy 1978). The plagioclase in the phyllite, homogenous amphibolite, quartz-mica schist and garnet-mica schist is typically untwinned. The untwinned nature of these crystals of plagioclase may be related to the grade of metamorphism (Philips 1930; Turner 1951; Ekwueme and Onyeagocha 1982). Twinning is, however, observed in the garnet-sillimanite and kyanite-sillimanite schists, gneisses, migmatites and banded amphibolites. Among the twins, albite and pericline are dominant. The composition of the twinned plagioclases varies from An_{25} to An_{30} in schists and gneisses and from An_{36} to An_{40} in the banded amphibolites and migmatites. The untwinned plagioclase in the phyllite, homogenous amphibolite, quartz-mica schist and garnet-mica schist is judged to be albite.

K-feldspar is subordinate to plagioclase where they occur in the gneisses and schists. Most crystals are typically untwinned but exsolution lamellae are abundant in few twinned K-feldspar. In most samples, the K-feldspar is in physical contact with alumino-silicate and garnet though not necessarily at the same location. K-feldspar in high grade pelites e.g. garnet-sillimanite schist is orthoclase whilst

microcline is dominant in biotite-hornblende gneiss (cf. Evans and Guidotti 1966). At some contacts of K-feldspar and plagioclase, myrmekite is observed.

Phyllosilicates make up 50 to 68 percent of the phyllite, quartz-mica and garnet mica schists. The abundance of these phyllosilicates especially chlorite and muscovite decreases with increasing grade of metamorphism. Muscovite is absent in the garnet-sillimanite schists but biotite makes up 67 percent of the phyllite. The phyllosilicates occur in two textural habits:

- (i) foliation defining groundmass laths and
- (ii) megacrysts.

The foliation defined by parallel alignment of chlorite, biotite and muscovite is occasionally disturbed by the porphyroblastic crystallization of garnet, kyanite and sillimanite. Generally, these phyllosilicates usually wrap around the porphyroblasts giving rise to pressure shadows (Figure 13). Minor folding of the phyllosilicates is apparent both in hand specimen and in thin section. In the quartz-mica schist, biotite develops on muscovite whereas it develops across the foliation in other schists. This textural evidence suggests two periods of development of both biotite and muscovite. Muscovite crystals up to 2cm across, commonly



Figure 13 : Phyllosilicates wrapping around
kyanite porphyroblast in the
kyanite-sillimanite schist (XPL; X 10)

lying at high angles to the foliation, occur in some schists and gneisses. These crystals which occur as Porphyroblasts (unusual texture) have other muscovite crystals forming a trail around them (Figure 14). This is an evidence of shear and suggests that granulation and recrystallization occurred as shown by the recrystallized fine-grained mortar. The porphyroblastic muscovite appears to form by recrystallization and coalescence of the muscovite in the groundmass. Unstable muscovite is observed in the migmatite (Figure 15).

Biotite offers favourable site for the nucleation of the Fe-Mg minerals, for example, hornblende in gneisses and the aluminosilicates with which they are always closely associated. Pleochroic haloes are common around small zircon inclusions in the biotite indicating radioactive bombardment from the enclosed zircon (Figure 16) (Onyeagocha 1984, p.44).

Retrograde chlorite is greenish in colour and with biotite define the foliation in few sections. In most sections, it occurs as fan-shaped crystal aggregates cutting across the foliation and forming intergrowths with and embayments on biotite.

Garnet in the area could be grouped under the three types discussed in Spry (1969, p. 270-271). These are pre-tectonic crystals (shattered and chloritized), syntectonic crystals



Figure 14 : Porphyroblastic muscovite in the biotite
hornblende gneiss (PPL; X 10)



Figure 15 : Unstable muscovite in the migmatitic
gneiss (PPL; X 10)



Figure 16 : Pleochroic haloes around zircon
crystal in biotite (XPL; X 10)

(rounded with S-shaped inclusion) and post-tectonic crystals (homogenous and does not disturb the foliation). The garnet in the phyllite and garnet-mica schist (Figure 17) corresponds to the first group whereas those in the higher grade schists and gneisses fall under the second and third types. Pigage (1982) observed that garnet porphyroblasts usually outline stages of growth. The first stage garnet forms large, ragged grains with inclusions of quartz, plagioclase, mica, and opaque dusting and the garnet in the garnet-sillimanite schist of Uwet area corresponds to this stage (Figure 12). The garnet in the garnet-mica schist occurs as clear, idioblastic porphyroblasts with minor inclusion and corresponds to Pigage's second stage garnet (Figure 17). Microfolding around garnet porphyroblast is rampant in thin section. The phyllosilicates form internal and external S-trail in and around the garnet porphyroblasts (Figure 12). The Si-Se trails are evidence of polyphase deformation. In the lower grade schists, garnet is zoned (Figure 17) possibly due to continuous garnet-forming reaction during prograde metamorphism (cf. Tracy et al. 1976). Homogenization at higher temperature possibly eliminated zoning (Figure 12) in the garnet of higher grade schist (Woodsworth 1977).

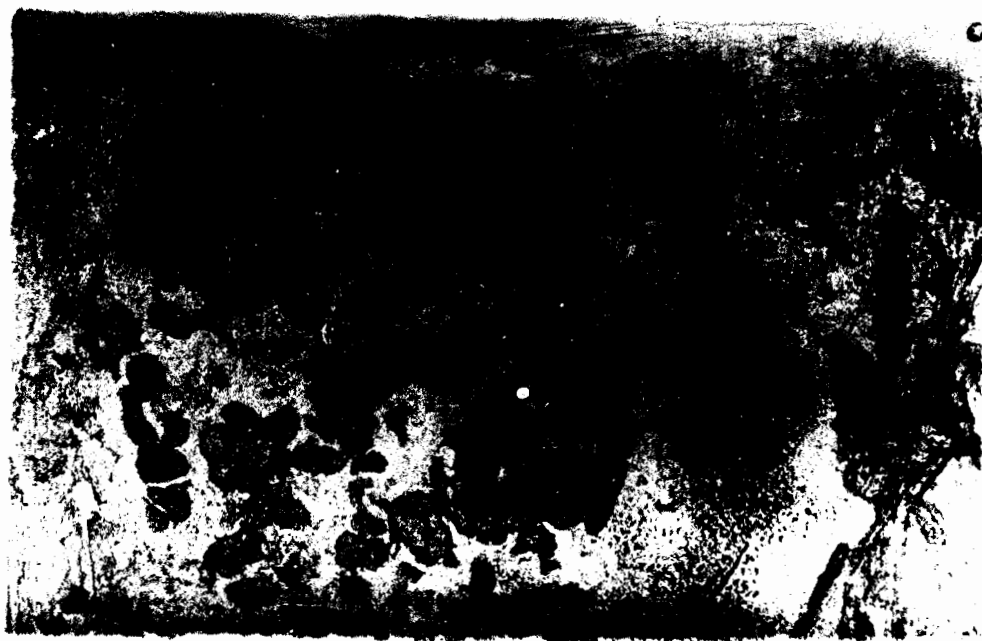


Figure 17 : Garnet with minor inclusion
of opaque dust in the garnet-mica
schist (PPL; X 10)

Kyanite forms equant shaped porphyroblasts in schist and gneiss. It enhances the foliation in kyanite gneiss (Figure 18) but deflects the foliation in kyanite sillimanite schist (Figure 13). Textural evidence indicates that kyanite seems to form at the expense of garnet and muscovite hence the garnet appears to have been almost used up to form kyanite and sillimanite in Sample KW₃ (Table 1). Kyanite does not show any tendency of breakdown or transformation to sillimanite. Both minerals coexist side by side in thin section.

Sillimanite varies in habit from radiating bundles of fibres (Figure 19) in the garnet-sillimanite schist and migmatite to relatively large, idioblastic, elongate, prismatic crystals in the kyanite-sillimanite schist (Figure 20). Fibrolite and coarse idioblastic sillimanite coexist in the kyanite-sillimanite schist (Figure 21). The texture shows that the fibrolite is coarsening to idioblastic sillimanite probably by grain growth (cf. Chinner 1961). Both minerals are intimately associated with biotite and this corroborates the view of Chinner (1961) that biotite provides a favourable site for sillimanite nucleation. Furthermore, there is a marked reduction in the modal volume of garnet in the sites where sillimanite formed. In KW₃ where sillimanite makes up 20 per cent of the rock no garnet was observed but in KW₅ and KW₆



Figure 18 : Kyanite sandwiched in biotite crystals
and enhancing the gneissosity of the
kyanite gneiss (XPL; X 10)

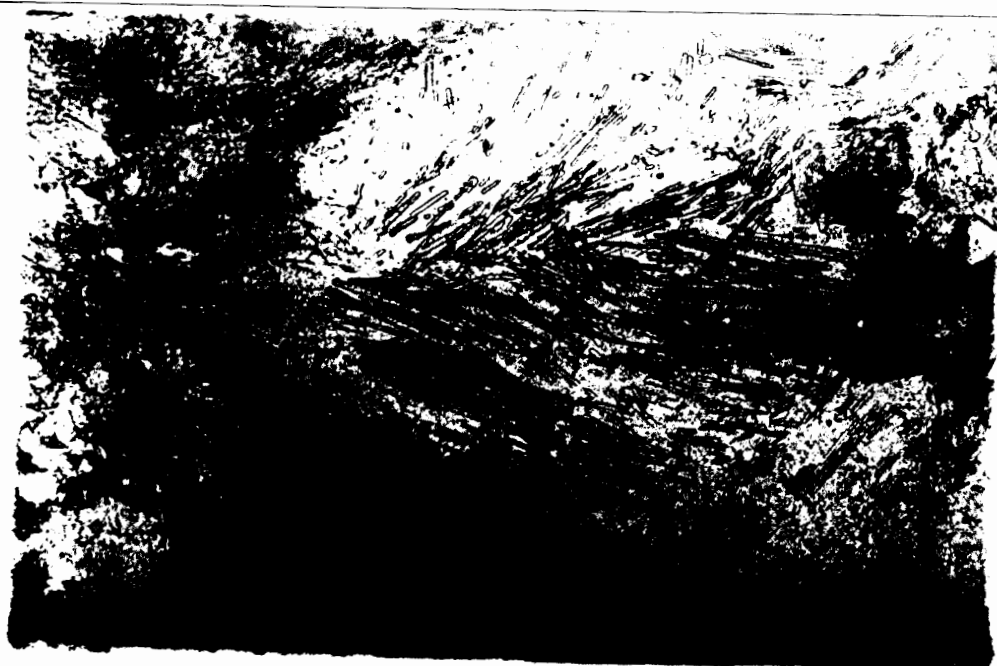


Figure 19 : Fibrolite in the garnet-sillimanite
schist (PPL; X 40)



Figure 20 : Elongate prismatic sillimanite in the
kyanite-sillimanite schist (XPL; X 10)



Figure 21 : Fibrolite coexisting with the idioblastic sillimanite in the kyanite-sillimanite schist (PPL; X 40)

where garnet occurs, only 4 and 2 percent sillimanite were observed respectively. Hence the sillimanite must have used up the garnet for its formation as shown in the reaction:

garnet + muscovite = biotite + sillimanite suggested
by Yardley (1977).

Green hornblende is abundant in the homogenous amphibolite and biotite-hornblende gneiss whereas the brownish variety forms over 70 percent of the banded amphibolite. In all sections, the hornblende is coarse-grained in texture. It is associated with epidote in the homogenous amphibolite and some gneisses. The banded amphibolite is epidote-free. Hornblende crystals often align themselves parallel to biotite thereby enhancing the foliation of the rock.

Epidote is observed replacing hornblende in some sections of hornblende-biotite gneiss. In one section, tensionally fractured epidote encloses a metamict phyllosilicate (Figure 22). Sphene is typically wedge-shaped in form, brownish in colour and shows a recognizable cleavage. It encloses some opaque minerals in few sections.

Secondary calcite occurs in biotite-hornblende gneiss and the dark portion of the kyanite-sillimanite schist. It is particularly common in the latter making up 20 to 30 percent of the rock (for example, sample Nos. KW₁, KW₅ and KW₆, Table 1).



Figure 22 : Fractured epidote enclosing an
allanite crystal in the biotite-
hornblende gneiss (XPL; X 10)

3.2 INTRUSIVE ROCKS

Table 5 shows the modal composition of the two main intrusive rocks in Uwet sheet namely dolerite and granitoid rocks.

DOLERITE:

The only dolerite outcrop in the area is composed of olivine (8%), pyroxene (44%), plagioclase (45%) and opaque oxide (3%) (vide Tables 4 and 5). The olivine occurs as equant aggregates dissected by cracks of different orientation. Zoning is rare in the olivine crystals. The plagioclase is a labradorite varying in composition from An_{55} to An_{60} . They are lath-shaped and some plagioclase laths are completely enclosed in pyroxene thus displaying the characteristic ophitic texture of dolerites. Some of the plagioclase crystals are strongly zoned. Gamble (1982) attributes such zoning in dolerite plagioclase to fluctuating P-T conditions during crystallization. Albite-carlsbad twins predominate in the plagioclase. Plagioclase occurs both as phenocryst and matrix of the dolerite. The pyroxenes are colourless but a few crystals display faint pleochroism under the microscope. Augite has well-marked partings which are more prominent than the cleavage. Plates of iron oxide are distributed along the partings. Hypersthene is elongated, has parallel extinction and is characterized by fewer partings than the augite.

TABLE 5 : MODAL COMPOSITION OF INTRUSIVE ROCKS IN UVER AREA

MINERALS	DOLERITES		GRANITE / GRANODIORITE										DIOCRATIC GRANITES		
	A ₁	A ₂	Q ₁	V ₂	AN ₂	AN ₃	W ₁	X ₂	X ₃	X ₆	OR ₂	W ₄	AV ₂		
Quartz	-	-	25	30	5	20	25	20	20	22	34	25	20		
Plagioclase	45	45	25	23	15	25	24	24	25	23	20	10	15		
K-feldspar	-	-	16	9	-	9.5	10	16	15	15	16	40	40		
Biotite	-	-	16	30	45	24	15	15	15	14	-	15	10		
Hornblende	-	-	12	4	-	15	-	15	15	16	-	-	-		
Epidote	-	-	1	-	-	1.5	-	5	5	6	-	X	-		
Muscovite	-	-	-	-	30	-	20	-	-	-	-	10	15		
Sphene	-	-	4	4	-	4.5	5	5	5	4	-	-	-		
Myrmekite	-	-	X	-	-	0.5	-	-	-	-	-	-	-		
Tourmaline	-	-	-	-	-	-	1	-	-	-	-	X	-		
Olivine	10	6	-	-	-	-	-	-	-	-	-	-	-		
Pyroxene	40	48	-	-	-	-	-	-	-	-	-	-	-		
Opaques	5	1	-	-	5	-	-	-	-	-	-	-	-		

X = PRESENT

Occasionally, both augite and hypersthene mantle the olivine crystals giving rise to corona texture. Emmett (1982) interpretes coronas in dolerite within a metamorphic terrain similar to the one under study as products of post-solidification deuterism, possibly active at high pressures and temperatures, rather than product of prograde metamorphism.

According to him, the coronas are due to a reaction between:

- (1) olivine or clinopyroxene and plagioclase and
- (2) oxide grains and plagioclase.

His interpretation may be valid for the study area in view of the fact that the dolerite is emplaced as a dyke (Figure 5) cutting across kyanite gneiss. However, normal igneous reaction during magmatic crystallization could have given rise to the formation of coronas.

The mineralogical evidence for the tholeiitic character of the dolerite is provided by the coexistence of Ca-rich and Ca-poor pyroxene. It has both olivine and hypersthene in the mode and according to Carmichael et al. (1974) there is often a very good correlation between the mode and the norm in such intrusive rocks. The CIPW norm of the dolerite shows that olivine and hypersthene occur in the norm of the dolerite thereby placing it in the group of olivine tholeiites. Such tholeiitic magma usually segregate from crystal mush at a depth of 0-15km in the mantle (Green and Ringwood 1967) after 20 or more percent degree of partial melting of the mantle peridotite

(O'Hara 1968; Ringwood 1975).

GRANITOID ROCKS:

The modal abundances of the Uwet granitoids were plotted on the Quartz-Alkali-feldspar-Plagioclase (QAP) diagram for plutonic rocks after Streckeisen (1976). The plots (Figure 23) indicate that the rocks range from granodiorite to granite in composition.

Quartz plus feldspar are the dominant minerals in the granodiorite. Single grains and aggregates of quartz appear to have been assimilated from the metasediments during the emplacement of the rock. They occur as resistant phases up to 1cm in diameter and appear as phenocrysts peppered throughout the rock. K-feldspar (microcline) is subordinate to plagioclase and may be square or rhomb-shaped in smaller crystals and tabular or rectangular attaining a length of 3.5cm in larger crystals. Most of the microcline crystals are perthitic and exsolution lamellae are common. Often they give rise to myrmekite. The plagioclase is an oligoclase-andesine ranging in composition from An_{28} to An_{32} . Some of the plagioclase crystals show weak zoning. Twinning is common and is mostly on the albite and albite-carlsbad laws. Alteration of plagioclase to sericite is rampant in the granodiorite.

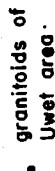


Fig. 25 Modal abundances of the Uwet granitoids plotted on the QAP (quartz, alkali feldspar and plagioclase) diagram for plutonic rock classification (Streckeisen, 1976).

Greenish brown hornblende is common in the rock. It is intimately associated with biotite, epidote and apatite. Unlike some foliated granitoid rocks in the Nigerian basement complex, these minerals do not show preferred orientation in thin section. The Uwet granodiorite is unfoliated. Muscovite occurs as an additional phase in few specimens e.g. UW1. The petrography of the granodiorite indicates that the original rocks might have been tonalite consisting of oligoclase, quartz, hornblende, biotite, sphene and only minor K-feldspar. However, contamination and/or potash metasomatism has substantially altered this and rendered the pluton compositionally variable.

Xenoliths and dyke rocks in the granodiorite of Uwet area show variable composition. The most conspicuous of the mafic xenoliths is the Igbofia meladiorite which occurs as xenolith trains within the Uwet granodiorite. Under the microscope, it is composed, where uncontaminated, of calcic plagioclase (An_{70}), hornblende, minor quartz, apatite and sphene. But digestion of metasediments, seen as xenocrysts, has introduced additional quartz, sphene, apatite and allanite changing the bulk composition to melatonalite.

A light-coloured dyke (AH2) in the granodiorite at Ahumi (Figure 4) is composed of quartz (5%), altered plagioclase (15%), biotite (45%), muscovite (30%) and opaque oxide (10%)

The rock is deformed and possibly older than the host granodiorite. Petrographic study shows that the dyke is very fine-grained and foliated. The foliation is disturbed by flakes of muscovite.

The meladiorite and the light-coloured dyke could be older plutons than the granodiorite and it is possible that the metasediments had already been deformed at least once before the intrusion of the meladiorite and the dyke.

In thin section, the granite is coarse-grained and non-foliated. It is composed dominantly of quartz and K-feldspar (Table 5). It also carries biotite with abundant pleochroic haloes and muscovite. The plagioclase is untwinned albite and it is intensely altered to sericite. Assimilation of some basement rocks, for example schists, has contaminated some of the granite. Some specimens are tourmaline-bearing.

On the whole, the Igbofia meladiorite, the light-coloured dyke in Ahumi and the granodiorite in Uwet area seem to have been emplaced by a reactive stoping mechanism presumably aided by high fluid contents evolved in the late stages of crystallization as alkali-rich fluids localized as pegmatites, dyke rocks and K-feldspar megacrysts. Metasomatism might have played a role in the formation of the meladiorite

(cf. Bishop and French 1982). According to these authors, the metasomatic process giving rise to the formation of the meladiorites takes place during a period of slow cooling between say 800°C and 600°C after the emplacement of granodiorite.

The granite, (sensu stricto) could be a product of regional anatexis due to high grade metamorphism. Evidence for this includes the association of the granite with rocks of highest grades of regional metamorphism, for example, banded amphibolite and migmatite. The partial digestion of the basement rocks in the granite is also an evidence of partial melting of the surrounding rocks (cf. Onyeagocha 1984, p.50).

CHAPTER FOUR

STRUCTURAL GEOLOGY

The Nigerian Basement complex is believed to have undergone polyphase deformation during the Precambrian (Oyawoye 1964; McCurry 1976; Rahaman 1976; Onyeagocha 1984). The latest of the deformation episodes occurred during the Pan-African orogeny (600 ± 150 Ma).

As a result of its polyphase nature, complex structures are associated with the Nigerian basement. These structures display different orientations depending on the deformational episode that produced them. Because of its high intensity, some authors believe that the Pan-African orogeny which was the last deformational episode obliterated earlier structures in the basement rocks of Nigeria (see Jones and Hockey 1964; McCurry 1976; Rahaman 1976). However, Onyeagocha and Ekwueme (1982) showed that abundant pre-Pan-African structures exist in parts of the basement complex. These structures, according to them, are characterized by orientations which are quite distinct from the N-S structures produced by the Pan-African deformational episode.

Three other thermotectonic events apart from the Pan-African have been recorded in the Nigerian basement complex. These are the Liberian (2800 ± 200 Ma.), the Eburnean (2200 M.a.)

and the Kibaran (1100 $\pm$ 200 Ma) (Oversby 1975; Grant 1971; Grant et al. 1972; Ogezi 1977). The pre-Pan-African structures could be imprints of any of these earlier events.

4.1 FOLIATIONS:

The rocks of Uwet area display variable foliation trends (Table 6). A plot of the foliation readings is shown in Figure 24. The plot shows two dominant trends in the NE-SW (0 $^{\circ}$ -40 azimuth) and the NW-SE (100 $^{\circ}$ -140 $^{\circ}$ azimuth) directions. Each of these trends represents imprints of a deformational episode in the area.

The result of the Pan-African deformation is a foliation trend largely 0-30 $^{\circ}$ azimuth (Onyeagocha and Ekwueme 1982). This is the dominant trend of foliation in the Uwet area and this foliation dips in the W, N.W. or S.E. directions. It is recognized in the phyllite, schists, gneisses and the homogenous amphibolite. This regional trend shows that the rocks in the area were affected by the Pan-African orogeny.

Foliation trends of 50-80 $^{\circ}$ azimuth occur but are less prominent than the 0-30 $^{\circ}$ azimuth trend. Such foliation trends (50 $^{\circ}$ -70 $^{\circ}$ azimuth) were interpreted as indicative of earlier deformation than the Pan-African by Onyeagocha and Ekwueme (1982). A foliation trend of 50-80 $^{\circ}$ azimuth was recorded in the schist at the Kwa Falls. In this area, however, a foliation trend of 40 $^{\circ}$ azimuth was also recorded and this foliation

TABLE 6

TRENDS OF GEOLOGIC STRUCTURES

JOINTS	FOLDS/ FAULTS	VEINS/ DIKES	FOLIATION	LOCATION
90°, 50°, 355°, 350°, 30°, 90°, 310°, 250°, 198°, 20°, 350°, 315°, 100°, 130°, 140°, 130°, 280°, 40°, 155°, 70°, 50°, 320°, 345°, 40°, 120°, 360°, 45°		62°, 90°	360°, 10°	Ikot, Ogora, Ikot Ana, Ahum
005°, 010°, 024°, 032°, 038°, 046°, 105°, 110°, 140°, 150°, 152°, 260°, 270°, 270°, 270°, 274°, 280°, 290°, 300°, 300°, 300°, 340°, 344°, 315°, 360°, 012°, 102°, 110°	42°, 40°, 90°, 270°	90°	42°, 40°, 40°, 44°, 360°, 005°, 360°, 30°, 360°, 360°, 360°	Akumaka, Ogung, Okon Ita, Ikwere, Ogora, Ikot, Ogora, Ikot, Ogora
200°, 136°, 076°, 288°, 064°, 248°, 286°, 160°, 086°, 322°, 226°, 310°, 326°, 358°, 220°, 322°, 327°, 270°, 40°	20°, 30°		20°, 350°, 20°, 30°, 300°, 20°, 320°	Okoro- Estate, Ikot Ikot
20°, 315°, 20°, 120°, 130°, 142°, 250°, 130°, 360°, 184°, 194°, 301°, 326°, 318°, 318°, 294°, 170°	250°, 70° 0°, 360°	326°, 50°, 4°, 116°, 220°	360°, 004°, 320°, 350°, 320°, 40°, 50°, 20°, 100°, 42°, 315°, 315°, 50°, 50°, 40°, 22°, 30°, 20°	Awk, Ayieban, Ikumaka, Okon Okoro, Okon Quarry, Ike Falls, Abba.
99°, 300°, 296°, 158°, 124°, 158°, 290°, 286°, 148°, 138°, 309°, 283°, 182°, 240°, 345°, 342°, 275°, 320°, 360°, 310°, 100°, 78°			315°, 25°, 315°, 40°, 20°, 320°	Agbani, Ikot Okoro, Ikot Ikot

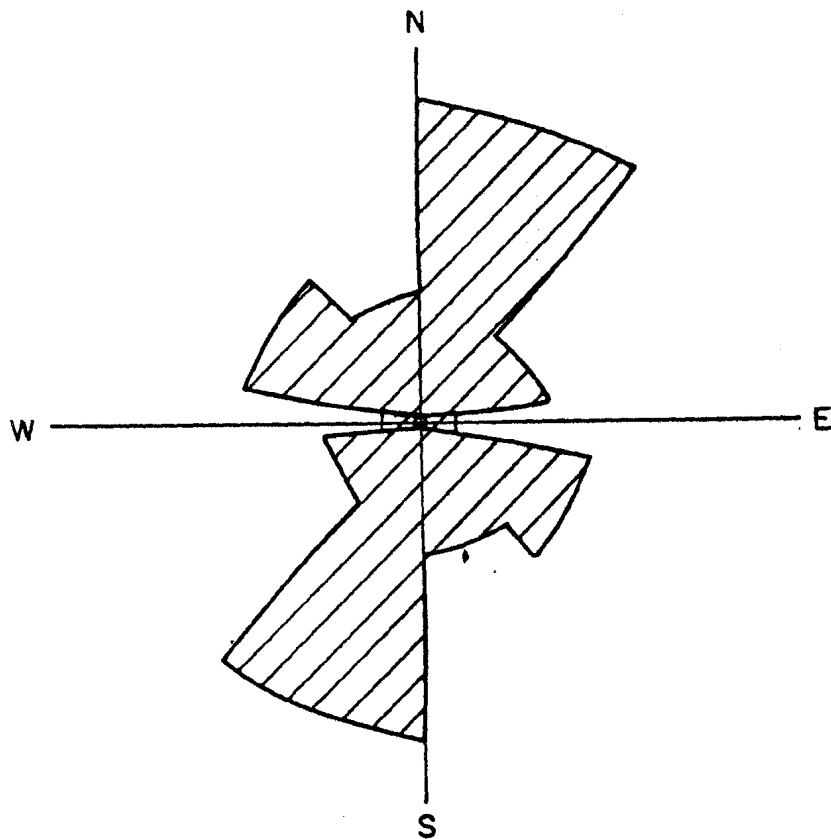


Fig. 24 Plot of strikes of foliations
of rocks in Uwet area.

transects the $50-80^{\circ}$ azimuth trend. The schists in the Kwa Falls therefore possess imprints of at least two deformational episodes which were separated in time. These episodes may belong to the same Pan-African orogeny in which the 40° azimuth trend represents a foliation produced by a later phase whereas the 50° azimuth trending foliation belonged to the earliest phase of the orogeny. Isotopic dating discussed later confirms this assertion.

There is a regional trend of foliation in Uwet area in the NW-SE direction with a low dip in the NE.

In the rose diagram (Figure 24) this foliation is of less magnitude than the $0^{\circ}-40^{\circ}$ azimuth trending foliation of the Pan-African. This foliation is recognized in many parts of the study area. It is observed in the gneisses at Calaro Estate, in the schists at Akwa Ibiami and in the migmatites at Mbarakpa. This foliation is the only type recorded in the banded amphibolite. The $100^{\circ}-140^{\circ}$ trending foliation is a strong evidence of a pre-Pan-African deformational episode (cf. Onyeagocha and Ekwueme 1982). In many localities where this foliation trend was recorded in Uwet area, it is often observed that the regional trend in $0-30^{\circ}$ off-sets the $100^{\circ}-140^{\circ}$ foliation. For example, in the Calaro Estate, the biotite-hornblende gneiss exhibits two sets of foliation trends. The first set which is conspicuous has a dominant $0-30^{\circ}$ trend with an attitude of

about 20° azimuth. The second set truncates the first and shows a trend in ~~NNW-SSE~~ direction with an attitude of 350° azimuth. The angle between these two sets of foliation is 30° . These two sets of foliation represent two different deformational episodes and the episode that produced the NNW-SSE trending foliation is judged to be pre-Pan-African.

Similarly, in Igbofia, the trend of the schistosity defined principally by biotite is NNE-SSW which is more or less N-S. Here, the quartzo-feldspathic veins define a second set of foliation in the NW-SE direction. Similar foliation off-sets were also observed in the migmatite at Mbarakpa and the schists in Agbangana.

4.2 FOLDS:

Rocks in Uwet area have undergone several episodes of folding. Minor folds of different orientation were mapped in the area. The dominant trend of fold axes is $0-30^{\circ}$ azimuth, a direction which is parallel to the regional foliation of the rocks. Such folds are related to the Pan-African orogeny. They were mapped in the schist at Abbiati, Ojo and Kwa Falls; the banded gneiss at Mbarakpa, Oban Okoroba and the Oban quarry (about 2km outside the map area in the east); biotite-hornblende gneiss at the quarry in Obung and the kyanite gneiss at the quarry in Old Netim. In most of these places, the folding is best studied in the pre-tectonic pegmatites, aplites

and quartz veins. They are all tight isoclinal folds with axes in the N-S and NE-SW direction. Most of the folds have variable plunges both in direction and amount. Their limbs usually have gentle dips.

At Abbiati, for example, the schist has been intensely folded. The fold which has an axis trending 32° azimuth is truncated by quartzo-feldspathic veins in the area. It offsets the foliation of the rock in some location. The fold axis in the banded gneiss at the Oban quarry trends 20° azimuth, again, parallel to the banding of the rock. Evidence of shear in the gneiss is the development of chloritic surface on each band of the gneiss. This surface constitutes a zone of weakness or cleavage along which the rock easily splits in bands. These folds are associated with numerous boudin structures. The boudins are abundant in both limbs of the folds, an indication that there was a great tension on these parts of the folds which tended to pull the limbs apart. The boudins (Figure 25), lie parallel to the foliation and the axes of the folds. This indicates that the foliation represents planes of weakness through which the quartzo-feldspathic material was ejected into the gneiss. Similar boudin structures were observed in the Kwa Falls.

The banded amphibolite is isoclinally folded. The fold axis trends 70° azimuth. The foliation is parallel to the banding in the parallel-folded rocks. This indicates that the



Figure 25 : Boudinage and associated folds in gneiss.

banding is older than the folds. Boudin structures are associated with the folds.

A minor fold with an axis trending in the 100° - 140° direction occurs in the Calaro Estate. Folds with axes trending 70° and 100° - 140° represent imprints of the pre-Pan-African folding episode.

A common feature in most crystalline rocks of Uwet area is ptygmatic folds. These are highly contorted quartzofeldspathic veins cutting across the foliation of the rocks. They were observed in the biotite-hornblende gneiss in Calaro Estate and in Obung, in the kyanite gneiss in Old Netim and the schist in Agbangana (Figure 26).

4.3 JOINTS AND FAULTS:

The rose diagram of the joints in Uwet sheet shows dominant trends in the NW, SE and NE directions (Figure 27). This multi-directional trend is an evidence of polyphase deformation. It is interesting to note that these are also the dominant trend directions of foliations. The joints in the area can be grouped into two : tension and compression types.

The tension joints are mostly associated with rocks showing NW-SE trending foliations. These joints were also observed in the dolerite dyke. The tension joints in the



Figure 26 : Ptygmatic folds in gneiss.

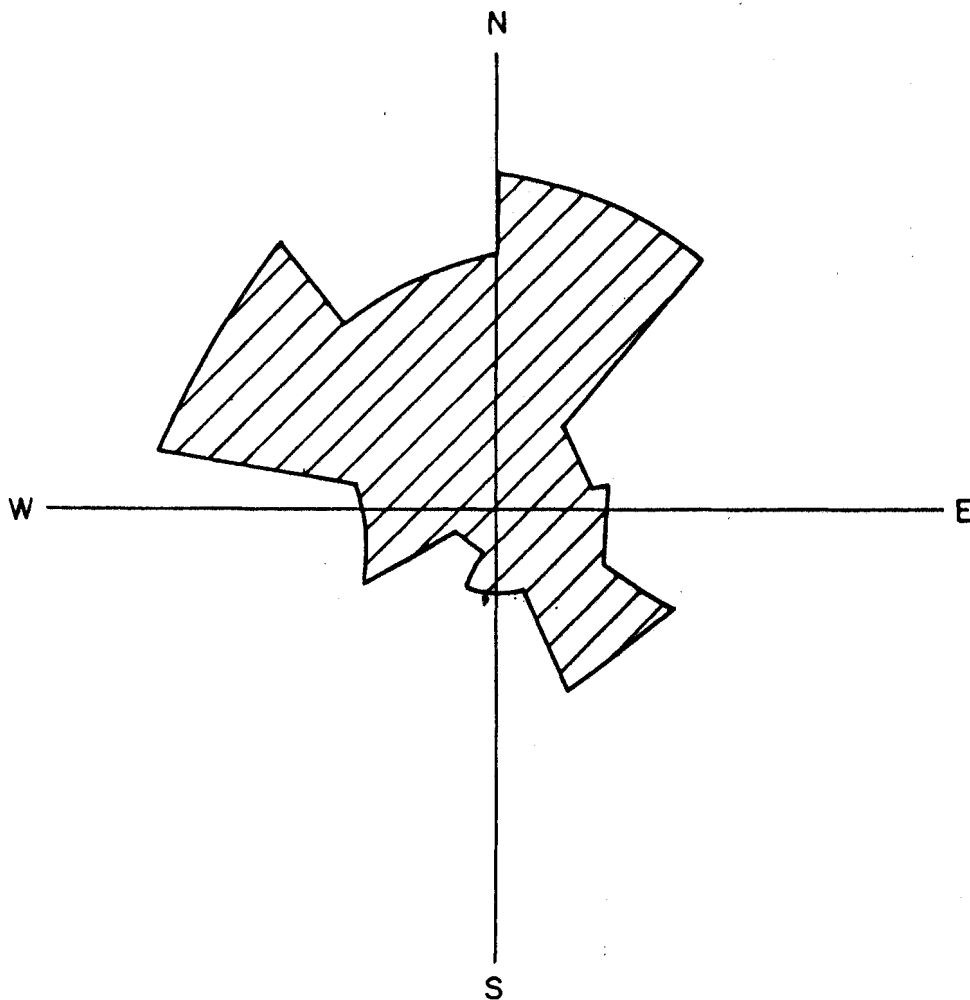


Fig. 27 Rose diagram of joints in
basement rocks of Uwet area.

metamorphic rocks of the area were possibly formed due to stress release associated with a dominant E-W tensional deformation which affected these rocks. In the dolerite outcrop in Old Netim, the joints were possibly developed as a result of the cooling and shrinking of the intrusion differentially thereby producing columnar and transverse joints. Rehealed fractures are associated with the tension joints in Uwet area (Figure 5). These fractures could have been tension joints before but were later widened to larger fractures. Shear and recrystallization of their host rocks (kyanite and biotite-hornblende gneisses) led to the in-filling of these fractures with materials which gave them a composition now different from their host rocks. These fracture-filling materials are schistose texturally and are dominantly composed of phyllosilicates of which chlorite predominates. The rehealed fractures are generally vertical and they occur in the kyanite gneiss at Old Netim (A7); biotite-hornblende gneiss in Obung (OB7) and in biotite-hornblende gneiss at Okom Ita. These fractures are products of tensional stresses which affected these rocks. The recrystallization of materials which now fill up the fractures were facilitated by volatile transport (cf. Walther and Orville 1982).

Compression joints in the Uwet area resulted from the tectonic (compressional) forces which acted on the rocks.

These joints have dominant trends in the N-S, E-W and NE-SW directions. They are the prominent joints in the phyllites and the schists of the area and could have been formed due to compression during the Pan-African orogeny.

A normal fault with an east-west direction was observed in the kyanite gneiss at the Old Netim quarry (Figure 28). The throw of the fault is about 2 metres and it was laterally displaced for about 4 metres. The east-west trend of the fault line is consistent with the fault's occurrence in a period of relaxation following a major deformation which affected the area. In the Obung quarry, faulting of the biotite-hornblende gneiss is inferred from minor displacements observed in the aplite and pegmatite dykes and veins (Figure 6). The displacements are in most cases not more than 4cm. Faulting is also inferred in the kyanite-sillimanite schist in the Kwa Falls and the banded amphibolite in Awi. At the Kwa Falls, there is a displacement of about 10 metres at the contact of the kyanite-sillimanite and garnet-sillimanite schists. The banded amphibolite was highly fragmented as the channel of the Erokut River is approached. Boulders of the rock are abundant in the channel and a displacement of about 19cm in a mafic dyke in the rock is an evidence of faulting in the area.



Figure 28 : Fault in kyanite gneiss.

4.4 MICROSTRUCTURES:

Thin section study revealed some microstructures especially in the schists of the area. Prominent among them are foliation, microfolding, S-trails in garnet and mortar texture. These textural features could be used to distinguish the different deformational and metamorphic events in these rocks and also to ascertain the order of crystallization of their minerals.

All the metamorphic rocks in the area possess preferred orientation defined by schistosity, gneissosity and banding. The foliation is usually defined by the parallel to sub-parallel arrangements of micas in the metasediments and hornblende in the amphibolites. In few cases for example, the schist at Agbagana, two sets of foliation were distinguished in thin section. This is an evidence of polyphase deformation which had already been confirmed by the trends of mesoscopic structures. In every section where these two sets of foliation were distinguished, the angle between them is about 30° which is consistent with the field data.

In thin section, the order of recrystallization was studied using the existence of pre-tectonic, syn-tectonic and post-tectonic crystals, for example, garnet. As it was shown in Chapter 3, all these three types of garnet occur in the schists of Uwet area. The pre-tectonic crystals are

usually wrapped by the foliation defined by biotite. In most cases, these biotites (Figure 17) are kinked and folded, an evidence that they have been deformed. The syn-tectonic garnet crystals (Figure 12) are also wrapped by foliation in some sections but they usually possess an internal S-trails (Si) that is discordant with foliation (Se). Spry (1969, p. 254) interpretes such features as indicative of repeated deformations. These Si-Se trails of garnet crystals can be recognized megascopically in the garnet-sillimanite schist where large garnet porphyroblasts (up to 3.0cm) occur. In thin section, the post-tectonic garnet crystals in the schists develop perfect forms of the crystal. They are homogenous and do not disturb the foliation of the rock. Similarly, large post-tectonic muscovite flakes in the schist follow the general direction of the foliation. Chlorite, generally grows across the foliation.

Spry (1969) is of the opinion that kyanite is generally post-tectonic and tends to be aligned along the layering. However, the kyanite and sillimanite in the schist at the Kwa Falls are wrapped by a folded foliation showing that they are pre-tectonic to this foliation (Figure 13).

Mortar texture in which large muscovite porphyroblasts are set in a fine-grained muscovite was observed in thin

sections of biotite-hornblende gneiss in Okom Ita (Figure 14). The larger crystals are possibly old relics now surrounded by new muscovite. This texture could have resulted from cataclasis and granulation of the rock, events which might be responsible for the development of rehealed fractures in the biotite-hornblende gneiss. In this rock, an older microfolded foliation is observed to have been cut across by a later foliation. This is an indication of polyphase deformation and polymetamorphism (cf. Spry 1969, p. 307 fig. 63).

4.5 DEFORMATION AND METAMORPHIC EPISODES

In a metamorphic terrain such as the Uwet area, the amount of deformation is estimated in a very approximate way from the size, number and types of folds or foliations produced (cf. Spry 1969, p. 311). The separate tectonic events are recognized mainly from mesoscopic structural evidence such as folds and foliations.

In Uwet area, the plot of foliations indicate dominant trends in the NE-SW ($0-40^{\circ}$ azimuth) and NW-SE ($100-140^{\circ}$ azimuth). The joints also show dominant trends in these directions. The rocks have been isoclinally folded in these directions. These mesoscopic structural trends are strong indications, that at least two episodes of deformation took place in the area.

The deformation episode that gave rise to the NW-SE trending structures was pre-Pan-African whereas the Pan-African orogeny left imprints of structures trending $0-40^{\circ}$ azimuth. However, Onyeagocha and Ekwueme (1982) observed that structural trend of $50^{\circ}-70^{\circ}$ azimuth in Akwanga area represents imprints of an earlier orogeny than the Pan-African. Such structures were observed in the Kwa Falls area where the schistosity of the kyanite-sillimanite schist trends 50° azimuth and in the Erokut River area where the fold axes in the banded amphibolite show a trend of 70° azimuth. However, in the Kwa Falls, the schistosity trending 50° azimuth transects another trending 40° azimuth. It appears that the schist has been subjected to at least two episodes of deformation separated in time during the Pan-African orogeny. If this is so, then the latest episode produced the 40° azimuth trending schistosity.

Spry (1969, p. 306) observed that multi-phase metamorphism (polymetamorphism) is suggested by

- (i) multiple foliations
- (ii) crystals which have complex time relations e.g. have discordant Si and Se,
- (iii) crystals which are post-tectonic to one foliation but pre-tectonic to another, or by a mineral species which has different forms or time relations in different crystals.

If the above criteria are applied to the rocks of Uwet area, it is evident that the area was not only subjected to multiple deformations but that the metamorphism was also multiple. Evidence of this is the multiple foliations in the $0-40^{\circ}$, $50^{\circ}-70^{\circ}$, and $100-140^{\circ}$ azimuth. The metamorphism appears to have occurred contemporaneously with or prior to the deformation. Evidence for this is provided by the migmatitic schists. In these schists which occur in the Kwa Falls and Abbiati area, the leucocratic and melanocratic portions were deformed in the same direction indicating that the migmatitization occurred prior to deformation.

If the deformation episode is represented by F, the foliation by S and the metamorphism by M, then the first deformation episode F1 in the area gave rise to S1 during or prior to M1. This resulted in the disruption of earlier beddings or original structures of the rocks and the recrystallization of such minerals as mica, quartz and plagioclase. During the second deformation episode (F2) this initial foliation was deformed resulting in bent micas particularly biotite which wrap around porphyroblasts such as garnet. This biotite formed the second foliation S2 possibly during or prior to M2. After or during the second deformation unstrained micas, kyanite, sillimanite and post-tectonic garnet formed due to continued recrystallization after F2. The evidence of

a third deformation (F3) in the area is provided by a foliation which wraps the post-tectonic kyanite in the kyanite-sillimanite schists (Figure 13). Spry (1969, p. 271) had argued that syntectonic kyanite is rare, if at all it exists, and that kyanite is invariably post tectonic in one metamorphic phase but may be pre-tectonic in multi-phase schists. It can therefore be argued that the foliation which wraps the kyanite in schist of Uwet area indicates that the kyanite was post-tectonic to F2 but pre-tectonic to F3 which produced the S3. This deformation affected the schist in the Kwa Falls area and possibly the schist in Abbiati and the banded amphibolite in Awi. It is the youngest Pan-African deformation episode in the area.

The possibility that these prograde events were separated by retrograde metamorphic events in between the deformation episodes is strong. Evidence for this is provided by the coexistence of cross-cutting chlorite and aluminosilicates in high grade schists and gneisses and the occurrence of muscovite in migmatites. The rehealed fractures exemplified by samples A7 and OB7 are also products of retrograde metamorphism. The retrograde event could have occurred during the period of quiescence following the deformations. It was aided by hydration or a decrease in temperature or both (cf. Abbot 1979; Corbett and Phillips 1981).

The observation that rocks of the Oban massif were subjected to polyphase deformation had earlier been made by Kemp (1981) and Onyeagocha and Ekwueme (1982). Kemp (1981) proposed that at least three phases of deformation/metamorphism affected parts of the Oban massif. According to him, two early phases are represented by an axial plane foliation (S2 ?) to tight isoclinal folds which cross-cut compositional banding (S1 ?) with an angular discordance of up to 30°. He observed that there is a correlation between fault, joint and fold axis orientation and outcrop pattern related to a third, more recent deformation.

Though the area studied by Kemp (1981) lies outside the area of the present investigation to the northeast, results obtained are indicative of three deformation and metamorphic episodes for the Uwet sheet.

CHAPTER FIVE

CHEMICAL COMPOSITION

5.1 ANALYTICAL METHOD:

Whole-rock analyses of representative samples from Uwet area were done using a Philips PW 1540 X-ray Fluorence Spectrometer and a Perkin - Elmer Model 306 atomic absorption spectrophotometer at the laboratory of the Illinois State Geological Survey, U.S.A.

Major oxides obtained by X-ray Fluorescence are SiO_2 , Al_2O_3 , Fe_2O_3 , CaO , K_2O , TiO_2 , and P_2O_5 . In the analysis by this method, the samples were dried at 105°C for one hour. 0.1250gm of each sample was mixed with 1.0gm $\text{Li}_2\text{B}_4\text{O}_7$ and 0.1250g La_2O_3 in a graphite crucible, covered and fused at 1000°C for 20 minutes. The fusion bead was then cooled, weighed and the fusion loss calculated. Fusion bead was crushed very fine with 2% somar mix, spread and tamped in a pressure vessel, covered with 3g somar mix, and pressed into a pellet at 40,000 psi. Pellets were stored in a desiccator until the end of analysis. A set of suitable NBS, USGS and synthetic standards were run with the samples and the concentration calculated using the XRF-4 computer program.

The determinations of Mg, Na, Mn and Zn were made using atomic absorption spectrophotometry. Perkin - Elmer single element hollow cathode lamps were used. A four inch slit burner head with an air/acetylene flame was used for Na, Mn and Zn and a two inch slit burner head with a nitrous oxide/acetylene flame was used for Mg. In the analysis, 0.1g of sample was weighed into 60ml acid washed linear polyethylene bottles. The sample was then treated with 1.5ml of aqua regia (1:3:1 - HN_3 : HCl : H_2O) and 2.5ml HF. The bottle was then capped tightly and placed on a steam bath for two hours. The digested sample was then treated with 25 ml of H_3BO_3 (50g/L) to complex the HF and 200ml CsCl solution (500,000mg/L (s) as an ionization suppressant and then diluted to 50ml with deionized water. This solution was aspirated into the flame. If the concentration of the analate in this solution was beyond the limit of linearity of the calibration curve, then the solution was diluted until the concentration fell within the limit of linearity. The calibration curve was constructed using synthetic standards made from ultra pure metals or compounds of the analate and matching the samples in their content of reagents. The curve itself was calculated using the method of least squares.

For the determination of ignition loss (LOI), 1.0g of sample was weighed into a 35ml platinum crucible. The sample was first dried at 110°C for two hours and then allowed to cool to obtain the dry weight of sample. The dried sample was then placed into a muffle furnace where the sample was heated to 500°C, uncovered. The temperature of the muffle furnace was then raised to 1000°C, and the sample was ignited at this temperature for 24 hours with the crucible covered. The sample was then allowed to cool and the weight recorded and the weight loss on ignition was calculated and reported as a percentage weight loss.

5.2. GEOCHEMISTRY

The chemical composition of rocks in Uwet area is presented in Tables 7 and 8. Table 9 presents the normative composition of these rocks. For the purpose of a discussion of the geochemistry of the rocks they have been grouped as follows:

- (i) Metasediments - phyllites schists and gneisses
- (ii) Meta-igneous rocks - amphibolites
- (iii) Basic rocks - dolerites
- (iv) Granitoid rocks - granodiorites, tonalites
- (v) Sedimentary rock - shales

TABLE 7 : AVERAGE CHEMICAL COMPOSITION OF ROCKS OF UWEI AREA, SOUTHEASTERN NIGERIA

	1	2	3(D)	3(L)	3(A)	4	5	6	7	8	9	10	11	12	13	14
SiO ₂	62.00	58.70	43.70	77.20	60.45	61.00	50.00	50.30	64.80	69.80	66.60	68.60	81.20	50.00	62.50	56.40
TiO ₂	0.85	1.11	0.81	0.11	0.46	0.80	1.26	1.15	1.11	0.58	0.64	0.05	0.51	2.33	0.77	1.52
Al ₂ O ₃	16.30	17.30	12.40	13.70	13.05	13.10	12.10	19.30	15.60	13.30	14.5	19.60	8.30	13.10	16.40	14.70
Fe ₂ O ₃ *	8.70	10.40	6.90	0.90	3.30	5.50	12.10	9.10	4.80	4.70	3.70	1.00	5.10	11.70	5.40	8.10
MnO	0.10	0.20	0.31	0.10	0.20	0.17	0.19	0.16	0.05	0.07	0.06	0.04	0.00	0.15	0.09	0.12
K ₂ O	3.82	4.29	7.71	2.30	5.05	2.29	8.86	4.42	1.56	0.77	1.72	0.13	0.29	7.42	2.66	4.54
CaO	0.40	1.90	10.00	0.60	5.40	5.90	8.30	5.70	3.20	2.20	2.90	0.40	0.10	0.60	4.00	4.60
MgO	0.98	2.21	0.85	0.50	0.68	2.82	1.82	4.25	3.88	2.73	3.49	5.19	0.08	3.34	3.58	3.10
Li ₂ O	4.50	3.29	4.50	3.30	3.90	1.88	2.36	3.32	3.53	4.49	3.70	2.65	2.40	0.77	3.62	3.84
FeO ₅	0.15	0.15	0.59	0.18	0.38	0.23	0.13	0.38	0.30	0.15	0.23	0.11	0.10	0.27	0.29	0.39
LOI	2.16	1.23	9.92	1.00	5.46	3.95	1.34	1.80	0.39	0.34	0.06	2.98	1.72	0.01	0.72	0.63

* Total Fe as Fe₂O₃

- 1: Garnet-sillimanite schist, 2: Garnet-sillimanite schist, 3(D) Biotite-sillimanite schist (dark portion), (3L): Biotite-sillimanite schist (light portion), 3(A) Average of the dark and light portions of Biotite-sillimanite schist
 4: Garnetiferous phyllite, 5: Homogeneous amphibolite, 6: Banded-amphibolite, 7 and 8: Biotite-hornblende gneiss, 9 and 10: Biotite gneiss, 11: Intruded sediment, 12: Dolerite, 13 and 14: Granitoid intrusive rocks.

TABLE 2 : SUMMARY. CHEMICAL COMPOSITION OF ROCKS OF UTAH AREA, SOUTHWESTERN NIGERIA

	Granite Gneiss				Banded Amphibolite				Homogeneous Amphibolite		Dolerite				Granitoid Rocks				Indurated Sediment
	A4	A41	A3	A5	A45	A41	A43		Ca1	Ca2	A1	A2	A3		X3	X2	U41	A43	
SiO ₂	66.60	66.60	56.59	69.60	50.30	50.00	50.60		50.00	50.00	50.00	49.40	50.60		62.50	62.50	56.40	57.00	61.20
TiO ₂	0.64	0.05	0.63	0.04	1.15	1.20	1.12		1.26	1.25	2.33	2.33	2.33		0.77	0.76	1.52	1.52	0.51
Al ₂ O ₃	14.50	19.60	14.50	19.60	19.30	19.20	19.40		12.10	12.10	13.18	13.00	13.20		16.40	16.35	14.70	14.70	8.30
FeO*	3.70	1.00	3.70	1.00	9.10	9.08	9.12		12.10	12.10	11.70	11.80	11.60		5.40	5.40	8.10	8.10	5.10
MnO	0.06	0.04	0.07	0.05	0.16	0.15	0.17		0.19	0.19	0.15	0.16	0.14		0.09	0.09	0.12	0.13	0.00
MgO	1.73	0.13	1.73	0.12	4.40	4.42	4.44		8.86	8.95	7.42	7.50	7.32		2.66	2.67	4.64	4.65	0.29
CaO	0.30	0.40	0.30	0.40	5.70	5.80	5.68		8.30	8.30	8.60	8.50	8.70		4.00	4.00	4.50	4.70	0.10
Na ₂ O	2.45	5.15	2.45	5.20	4.25	4.20	4.30		1.83	1.83	3.34	3.35	3.30		3.58	3.57	3.10	3.10	0.08
K ₂ O	3.70	0.15	3.70	0.55	3.32	3.30	3.34		2.35	2.35	0.77	0.79	0.75		3.62	3.61	3.81	3.87	0.40
FeO ₂	0.23	0.11	0.24	0.11	0.30	0.25	0.41		0.13	0.12	0.27	0.25	0.30		0.23	0.25	0.39	0.39	0.10
LOI	0.00	0.00	1.00	2.37	1.30	1.30	1.80		1.34	1.33	0.01	0.01	0.01		0.72	0.73	0.63	0.63	1.72
Si	20	20	20	19	33	116	28		33	33	122	130	132		115	116	50	50	-
Ca	200	150	200	199	73	91	82		93	93	104	105	102		82	82	109	110	-
Na	0	0	0	0	21	41	30		0	0	46	45	45		49	50	15	16	-
K	58	53	57	68	160	230	87		83	82	145	140	144		100	100	120	122	7

* Total Fe as Fe₂O₃

TABLE 9 : AVERAGE NORMATIVE COMPOSITIONS OF ROCKS IN UMET AREA S. E. NIGERIA

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Quartz	27.24	16.38	-	21.00	-	-	17.34	28.26	21.54	26.82	67.98	-	12.30	4.20
Orthoclase	26.69	19.46	25.58	11.12	13.90	20.02	21.13	26.69	22.24	15.57	14.46	4.45	21.68	22.80
Albite	8.35	18.86	-	24.10	15.72	26.29	33.01	23.06	29.87	44.02	0.52	28.30	30.39	26.20
Anorthite	1.11	8.62	16.96	17.51	18.07	23.91	14.46	10.29	12.51	1.11	-	18.35	17.79	15.01
Leucite	-	-	3.49	-	-	-	-	-	-	-	-	-	-	-
Nepheline	-	-	3.98	-	-	5.40	-	-	-	-	-	-	-	-
Corundum	9.49	7.04	-	-	-	-	0.10	0.20	-	7.45	5.61	-	-	-
Diopside	-	-	24.29	7.61	18.73	1.86	-	-	0.35	-	-	18.73	0.35	4.58
Wollastonite	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hypersthene	22.80	26.64	-	9.97	17.75	-	10.10	8.90	9.22	2.02	8.36	12.04	14.20	20.86
Olivine	-	-	13.22	-	10.22	15.56	-	-	-	-	-	9.59	-	-
Ilmenite	1.62	2.13	1.52	1.52	2.43	2.28	2.13	1.06	1.22	0.15	0.91	4.41	1.52	2.89
Apatite	0.93	0.93	3.72	1.86	0.93	2.79	1.86	0.93	1.86	0.93	0.62	1.86	1.86	2.79

- 1 - Garnet-mica schist; 2 - Garnet-sillimanite schist; 3 - Kyanite-sillimanite schist;
4 - Garnetiferous phyllite; 5 - Homogeneous amphibolite; 6 - Banded amphibolite;
7 and 8 - Biotite - hornblende gneiss; 9 and 10 - Kyanite gneiss; 11 - Indurated sediment;
12 - Dolerite; 13 - and 14 - Granitoid rocks.

The chemical compositions of rocks in Uwet area are compared with rocks of similar compositions in the literature (see Table 10).

METASEDIMENTS:

Comparison of the metasedimentary rocks in Uwet area with equivalent rocks in literature shows that the compositions of the garnet-mica schist, garnet-sillimanite schist and the kyanite gneiss approximate the composition of an average shale (cf. Clark 1924, Shaw 1956). The garnet-sillimanite schist and the kyanite gneiss have compositions close to that of the high grade pelitic rock analysed by Shaw (1956). As is characteristic of metapelites in the literature, these three rock types have an excess of potash over soda, high aluminium to alkali ratios and low calcium and magnesium contents. The minor difference between these metapelites and the composition of average pelitic rock is the higher content of iron in the garnet-mica and garnet-sillimanite schists. The difference could be accounted for by the modal proportions of the Fe-Mg-bearing silicates or by pyrite in the original pelite (Pettijohn 1975).

The composition of the kyanite-sillimanite schist is complex probably because of its migmatitic nature among other factors.

The melanocratic portion of this schist effervesces upon application of dilute acid. It contains secondary calcite. The melanocratic and leucocratic portions of the schist were separated and analysed. As shown in Table 7 (sample 3D) the melanocratic portion has a composition very different from an average high-grade pelitic rock of Shaw (1956). This portion has very low silica (43.70% SiO_2) and low alumina (12.40% Al_2O_3). These reflect the composition of the predominant biotite in the sample. The high lime content (10.00% CaO) and loss on ignition of 9.92% indicate the presence of secondary calcite. On the other hand, the leucocratic portion (sample 3L) is quite siliceous (77.20% SiO_2) pointing to the abundance of quartz and feldspar. It, however, still retains the condition $\text{Al} : (\text{Na} + \text{K} + 2\text{Ca})$ greater than unity which is required of a pelite as an Al-excess rock. It is this $\text{Al} : (\text{Na} + \text{K} + 2\text{Ca})$ greater than unity which permits the occurrence of Al-excess minerals, kyanite and sillimanite, in the leucocratic portion of the schist as opposed to the melanocratic portion where this ratio is less than unity.

The phyllite of Uwet area has a composition similar to that of an average greywacke of Pettijohn (1975). It has an excess of soda over potash which is characteristic of greywackes. The ratio of Na_2O to K_2O of the phyllite (3:2) is

comparable to the ratio 1.70:1 of Pettijohn's (1975) average of eleven greywackes (see Table 10). The minor differences in the composition of the phyllite and average greywacke is reflected in the modal composition of the phyllite (Table 1). It is observed that the ferromagnesian minerals (chlorite and biotite) constitute about 70 percent whereas K-bearing minerals for example, muscovite constitute only 2 percent of the phyllite. (Minor amounts of K may be present in plagioclase).

The biotite-hornblende gneiss has composition close to that of an average greywacke and granodiorite. There are slightly higher contents of lime and potash in the biotite-hornblende gneiss. In some outcrops of the gneiss (Table 7 and 8) potash is greater than soda whereas the reverse is the case in others. This variation in the ratio of potash and soda in metasediments, according to Pettijohn (1957), may be due to:

- (i) the mixed nature or association of two compositionally different lithologic units e.g. shale greywacke sequence as the parent rock;
- (ii) addition of materials through metasomatism;
- (iii) facies change.

Comparison of the composition of the gneisses in Uwet area with those reported in other parts of Nigeria indicates that they fall within the same compositional range.

The kyanite gneiss of Uwet area is distinct in having high content of alumina (19.60% Al_2O_3). This is reflected in the abundance of aluminosilicate mineral, kyanite (7%, Table I). On the other hand, the iron and magnesia content of the kyanite gneiss is lower than those of the gneiss in Iseyin area of Southwestern Nigeria reported by Rahaman (1978) and the granite gneiss in Ilesha area also in southwestern Nigeria discussed in Elueze (1982).

META-IGNEOUS ROCKS:

Two bodies of amphibolite were mapped in the area: the homogenous and the banded amphibolites. These two amphibolites are fairly similar in their silica and titanium content and in their ignition loss (see Table 7).

The banded amphibolite has a composition close to the ortho-amphibolite analysed by Van de Kamp (1969). Their lime, soda and iron content is similar whereas they differ in their content of alumina, potash and silica (Tables 7 and 10). The alkali and alumina content of the banded amphibolite is much higher than those of average of 200 amphibolites reported in Evans and Leake (1960, p. 354).

The homogenous amphibolite differs from the ortho-amphibolite of Van de Kamp (1969) in several ways: it has a much lower aluminium content but higher contents of iron, calcium and magnesium (Tables 7 and 10). On the other hand,

the composition of the homogenous amphibolite approximates closely the composition of the para-amphibolite of Blank (1972). Their silica, titanium, iron and soda content is very similar whereas they differ slightly in their alumina, magnesia and lime content (Tables 7 and 10). The peculiarities in the composition of the amphibolites in Uwet area may be due to the difference in the composition of their parent rocks. The homogenous amphibolite may be classified as a para-amphibolite whereas the banded amphibolite fits into the class of ortho-amphibolite.

Comparison with chemical data of amphibolites reported in Nigeria (for example, Freeth 1971 ; Olade and Elueze 1979; Elueze 1981b) indicates that both the homogenous and the banded amphibolites of Uwet area differ substantially in composition with these amphibolites particularly in their alumina and lime contents. This may again relate to differences in their progenitors. For instance, whereas the homogenous amphibolite of Uwet area fits into the para-amphibolite class and the banded amphibolite has a composition similar to a metamorphosed alkali-alumina basalt (Al_2O_3 is greater than 17 percent), Olade and Elueze (1979) and Elueze (1981b) classified the amphibolites in their area of study as metamorphosed tholeiitic basalt.

BASIC ROCKS:

The composition of the dolerite in Uwet area is fairly similar to that of an average dolerite given by Cox and others (1979). However, the Uwet dolerite differs from it by possessing slightly lower contents of lime and soda. This may be a reflection of the alkaline nature of the parent magma. On the other hand, the composition of the dolerite approximates that of normal tholeiite given by Evans and Leake (1960, p. 354) and that of an average of 137 normal tholeiitic basalt and dolerite given by Nockolds (1954). It has a lower lime but a higher soda content than these published analyses. Like tholeiitic dolerites, it has olivine and hypersthene in the norm (Table 9). However, its total alkali content of 4.11 weight percent is rather high when compared with alkali content of tholeiitic basalt of Hawaii which is 2.60 weight percent (cf. Hatch and others 1972). Metasomatism or assimilation of materials from the surrounding gneisses in which the dolerite was emplaced could account for this enrichment in alkali.

Hossain (1981) studied the dolerites in Ugep area which lies outside this study area to the west. Comparison of the composition of his dolerites with that of Uwet area shows that the two are fairly similar except for the higher content of alkali in Uwet dolerite and the higher loss on ignition in the Ugep dolerite. The high content of alkali in the Uwet dolerite

may be attributed to alkali metasomatism due to the rejuvenation of the basement rocks during the Pan African tectogenesis (cf. Oyawoye 1972). This led to enrichment of the dolerite in alkali. On the other hand, the emplacement of the Ugep dolerite in a wet sedimentary environment as opposed to a dry environment (metamorphic terrain) of the Uwet dolerite may explain the higher ignition loss of the former. The contact of the tholeiitic magma in Ugep area with wet sediments caused minor albitization. This was followed by carbonate-rich deuteric/hydrothermal fluids (Hossain 1981).

GRANITOID ROCKS:

The chemical data separate the granitoid rocks in Uwet area into two types: "tonalite" and granodiorite. The chemical compositions of samples X_2 and X_3 (Table 8) are similar to that of tonalite reported by Cox and others (1979). They are also chemically similar to the tonalite analysed by Dupuy and others (1982, p. 44) in the Adamello massif (Table 10). The slight differences between the bulk composition of the Uwet tonalite and that of Adamello massif are the higher contents of lime and a lower content of potash in the latter. K-metasomatism due to the rejuvenation of the basement rocks of Uwet area during the Pan-African tectogenesis may explain the high potash content (cf. Oyawoye 1972).

Other analysed samples (UWI and AH₃) are less siliceous than the tonalite. Their alumina and alkali contents are lower than those of the tonalite but they are enriched in iron, magnesia and lime. Their compositions approximate the composition of an average granodiorite (cf. Cox et al. 1979) except for their slightly lower silica and alumina and their slightly higher iron and magnesia contents. As was demonstrated in Chapter 2.2, the granodiorites in Uwet area contain mafic xenoliths of the country rock which might have been assimilated at the time of their intrusion. This may account for the high contents of iron and magnesia in the analysed granodiorite.

In relation to the nomenclature of Streckeisen (1976), the analysed granodiorites have modal compositions which plot into the granodiorite field in the QAP diagram (Figure 23). However, the modal compositions of the tonalite (X₂ and X₃) plot rather in the field of granite but very close to the granodiorite in the QAP diagram (Figure 23).

Both the tonalite and granodiorite of Uwet area are quartz-normative and display calc-alkaline affinities showing relatively high contents of Al₂O₃ and CaO but low TiO₂ and Fe₂O₃ (total)/MgO ratio.

SEDIMENTARY ROCKS:

A sample of an indurated shale analysed shows a high

silica content (greater than 80 percent). Comparison with similar rocks in literature reveals that the composition of the sediment (Table 9) does not fall into the quartzite clan of Middleton (1960). This is principally due to its high alumina content of 8.30 weight percent compared to the quartzite which has generally less than 5.0 weight percent Al_2O_3 . The composition of the sediment is close to the composition of a siliceous shale reported in Pettijohn (1975). As is characteristic of shale, the sediment has an excess of potash over soda and an excess of magnesia over lime.

Pettijohn (1975, p. 270) observed that the interpretation of chemical analyses of shales is fraught with considerable difficulty because the chemical composition is dependent on the grain size, on maturity of sediment, and on restoration by chemical or biochemical processes of many of the constituents removed by weathering during the production of residual soils from which sediment was derived. According to him, the coarser fraction is richer in silica whereas finer materials are richer in alumina, iron, potash and water. The high silica content of the indurated shale which covers the basement in Uwet town at the central part of the study area could be a reflection of the coarseness of its texture.

5.3 PETROGENESIS:

Chemical data (Tables 7, 8, 9) confirm that the geochemical evolution of Uwet area involved the metamorphism of rocks of different mineralogy and sources.

In addition to the comparison of the chemistry of these rocks with others of similar composition (see Chapter 5:2) various discriminants (e.g. diagrams) have been employed to unravel their geochemical evolution.

PHYLLITE:

The average composition of phyllite (Table 7) plots at the boundary of the fields of igneous and sedimentary rocks in the $\text{Na}_2\text{O}/\text{Al}_2\text{O}_3$ against $\text{K}_2\text{O}/\text{Al}_2\text{O}_3$ diagram (Figure 29) of Garrels and Mackenzie (1971). As a result, other chemical parameters such as excess of Na_2O over K_2O were integrated with the field and petrographic data to determine that the phyllite is of sedimentary origin.

Scotford (1956, p. 1181) observed that an important characteristic of the chemical composition of greywackes is the excess of soda over potash. This feature is indicated in Uwet phyllite where the ratio of $\text{Na}_2\text{O}:\text{K}_2\text{O}$ is 3:2. This falls within the range of $\text{Na}_2\text{O}-\text{K}_2\text{O}$ ratios found in analysed greywackes (Table 10).

When the chemical data of the phyllite are plotted on a SiO_2 Vs CaO variation diagram (Figure 30), the phyllite plots

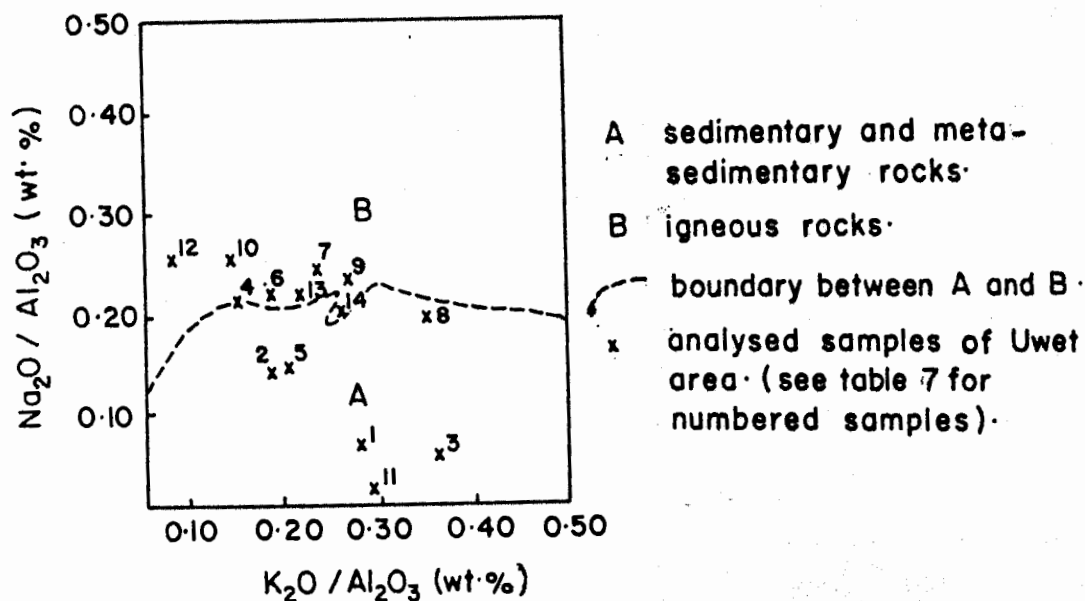


Fig. 29 Na_2O / Al_2O_3 against K_2O / Al_2O_3 plot
 for rocks of Uwet area. Indicated fields
 after Garrels and Mackenzie (1971).

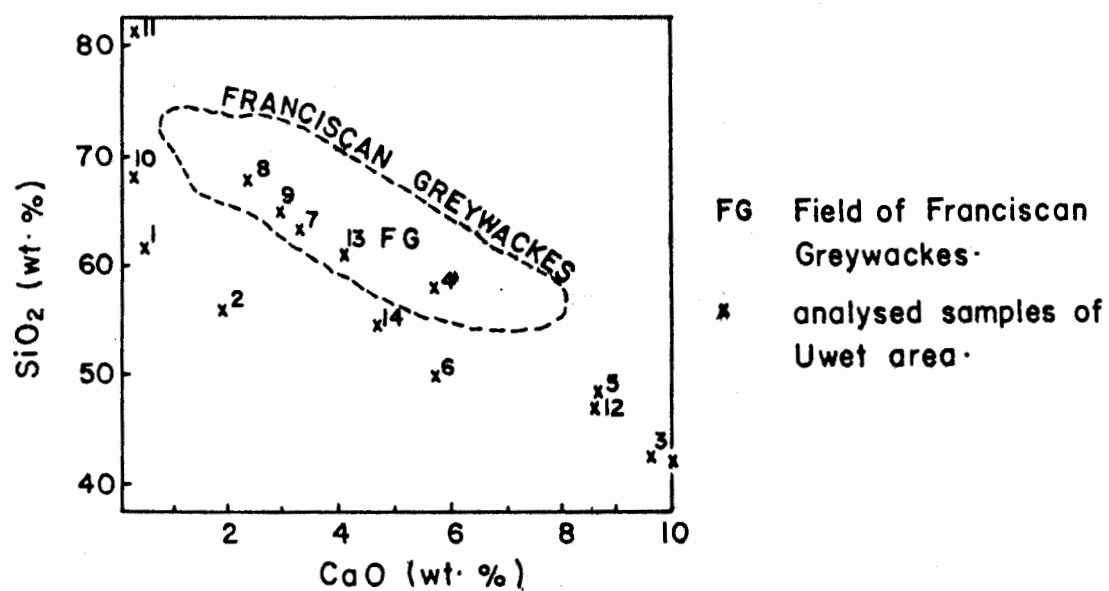


Fig. 30 SiO₂ - CaO variation diagram for the rocks of Uwet area. (Field of Franciscan greywackes after Brown et al. 1979).

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in the field of the Franciscan greywackes of Brown et al. (1976). It also plots in the field of eugeosynclinal sandstone of Middleton (1960). Middleton (1960, p. 1017) noted that eugeosynclinal sandstones are in fact the greywackes of Pettijohn (1957). On the ACF diagram of Winkler (1967), the phyllite plots on the field of greywacke (Figure 31).

SCHISTS:

As noted in the preceding section, potash is in excess of soda in all the analysed schists of Uwet area. There seems to be a consensus among geochemists and petrologists that, in general, potash usually exceeds soda in shale (Clarke 1924; Scotford 1956; Middleton 1960; Butler 1965).

When the average composition of the Uwet schists (Table 7) is plotted on the ACF diagram (Figure 31) it is observed that the garnet-sillimanite and garnet-mica schists and the leucocratic portion of the kyanite-sillimanite schist plot on the field of clays and shales either free of carbonate or containing up to 30% carbonate. (The melanocratic portion of the kyanite-sillimanite schist which has been shown to be contaminated with secondary calcite plots near the boundary of shales and clays and basaltic and andesitic rocks). MgO is in excess of CaO in these rocks possibly indicating the carbonate-free nature of their parent shale.

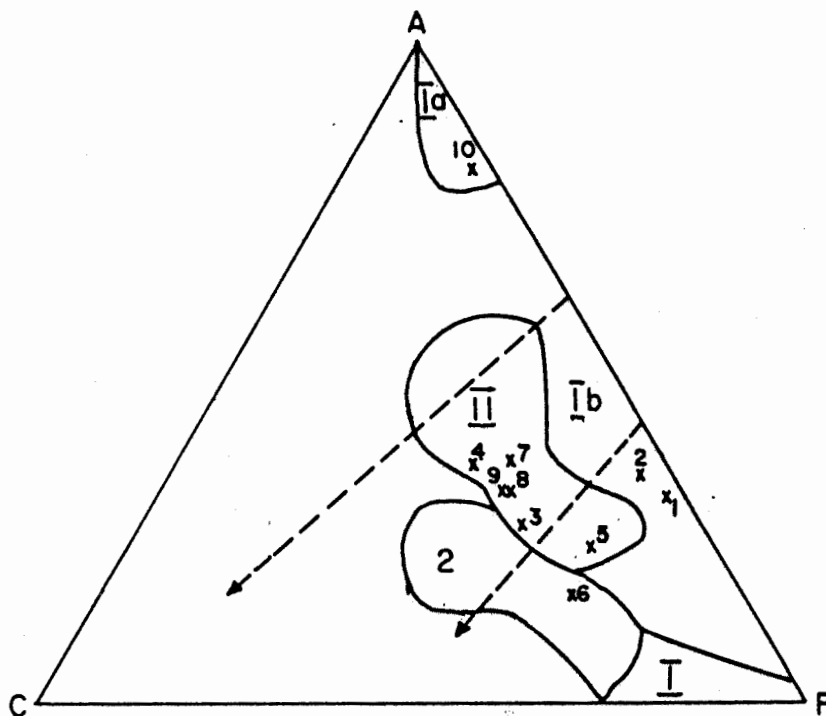


Fig. 31 Plot of Uwet rocks on ACF diagram.
(After Winkler 1967).

- Ia Al-rich clays and shales.
- Ib Clays and shales either free of carbonate or containing up to 30% carbonate between arrows marls containing 35-65% carbonate.
- II Greywackes.
- I Ultrabasic rocks.
- 2 Basaltic and andesitic rocks.
- x Uwet area.

Scotford (1956, p. 1183) argued that since the chemical composition of shale varies widely it is more significant that a metamorphosed argillaceous rock contains abundant alumina, has an excess of potash over soda and magnesia over lime as is typical of shales. The schists of Uwet area satisfy these conditions except for the melanocratic portion of the kyanite-sillimanite schist which approximates the composition of calcareous shale of Pettijohn (1975).

AMPHIBOLITES:

The differentiation of amphibolites of sedimentary and igneous origin has been a problem of petrologic interest.

The major problem has been whether amphibolites of igneous and of sedimentary origin can be distinguished by chemical analysis alone, either individually or in suites. Some investigators such as Leake (1964), Van de Kamp (1969), Bowes and Langer (1973) and Olade and Elueze (1979) are of the opinion that a distinction can be made from chemical data and variation diagrams. Among the parameters they used for this purpose include the low $\text{CaO}/\text{Al}_2\text{O}_3$ (< 0.27) and Rb/Sr (< 0.12) ratios of Van de Kamp (1968) for ortho-amphibolites. Other investigators such as Wilcox and Poldervaart (1958), Walker et al. (1960), Misch (1966), Orville (1969), Kesler and Kesler (1971) and Blank (1972, 1973) feel that field and petrographic evidence is of greater significance. They observed that in all plots of the chemical proportion of ortho- and

para- amphibolites (Leake, 1964; Van de Kamp, 1968; Preto, 1970 and Bowes and Langer, 1973) there is a great deal of scattering of the points and overlapping of igneous and sedimentary fields. They concluded that the trend lines must be rather arbitrarily drawn. Amphibolites whose analyses plot closest to the trend of igneous rocks are considered to be of igneous origin, and those "peripherally disposed" to be of sedimentary origin. Blank (1973) asked: "how far from the igneous trend must an amphibolite plot before it can be considered to be of sedimentary parentage?" Apparently, the more samples that are plotted, the more the gradation between ortho- and para-amphibolite there seems to be.

Blank's (1973) observation is applicable to some amphibolites reported in Nigeria. For instance, Olade and Elueze (1979) and Elueze (1981b) argued that the amphibolites in Ilesha and Tegna areas are of igneous origin based principally on geochemical interpretation, using Leake (1964) and Van de Kamp (1969) approach. The plot of their chemical data in all cases showed a scattering and overlapping of points as majority of the plots fell in the field of igneous rocks though some plot in the field of pelitic sedimentary rock. Also their $\text{CaO}/\text{Al}_2\text{O}_3$ value for the banded amphibolite is 0.65 (see Table 10) which is quite higher than the value of $\text{CaO}/\text{Al}_2\text{O}_3$ (< 0.27) required for ortho-amphibolites according to Van de Kamp (1969). In spite of

these discrepancies, Olade and Elueze (1979) on the basis of their chemical data interpreted all the amphibolites in Ilesha area to be of igneous origin. And in another paper, Elueze (1981b, p. 384) argued that chemical data show that the amphibolites of the Nigerian schist belts are similar in overall chemistry to Archean metabasalts and tholeiites.

This trend in the interpretation of the progenitors of amphibolites seems to have arisen from the conceptions held by such workers as Evans and Leake (1960), Leake (1964) and Van de Kamp (1968, 1969). For instance, Van de Kamp (1968, 1969 p. 1135) on finding that the chemical analyses of para- as well as ortho- amphibolites clustered about Leake's (1964) igneous trends suggested that "nearly all amphibolites are derived from basic igneous rocks, even if they appear as metasediments". Van de Kamp (1968) explained that the Ontario para-amphibolites could be derived from mafic tuffs deposited in an area of carbonate deposition. Earlier than this, Evans and Leake (1960) had argued that a metasedimentary origin for a rock of basaltic composition would require an unlikely mixture of sodium-rich greywacke and iron-rich dolomite. Other investigators using Evans and Leake (1960), Leake (1964), and Van de Kamp (1968, 1969) approach attributed igneous origin to amphibolites from many localities.

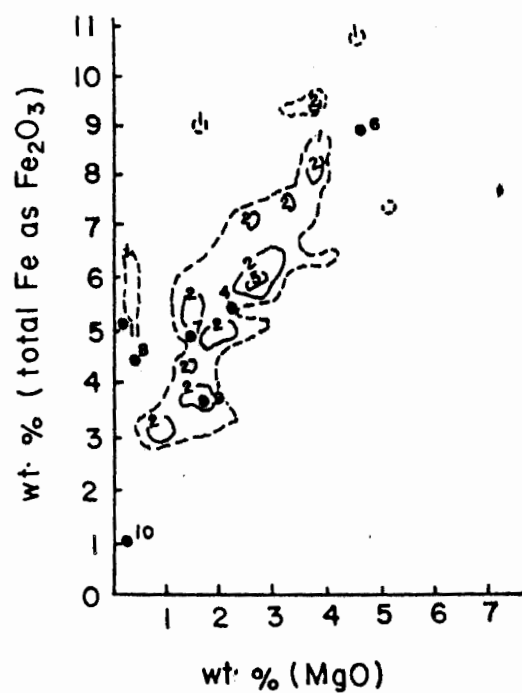
On the contrary, some petrologists still maintain that there are amphibolites of sedimentary origin. For instance, Orville (1969, p. 64) argued that "the composition data do not require an igneous parent for the amphibolite. Any rock, whatever its origin, composed chiefly of hornblende with a subordinate amount of plagioclase will approximate a basaltic composition".

He continued: "chemical reaction between carbonate-rich rock and carbonate-free pelitic rocks under open-system conditions can produce a hornblende-plagioclase assemblage from a wide range of carbonate-rich pelitic compositions. In this way, carbonate-rich layers in pelitic rocks, a common sedimentary assemblage, would be related to amphibolite layers in pelitic schist and gneiss, a common metamorphic assemblage". Blank (1972, 1973) in like manner, felt that the field and petrographic evidence strongly suggests the derivation of the hornblende schists in the Manhattan Formation in the Bronx, New York, U.S.A. from calcareous ferruginous beds in a sedimentary sequence and that his chemical evidence does not invalidate this conclusion. Blank's (1972) chemical data for the hornblende schist include:

- (a) the silica contents fall within a narrow range
- (b) the alkalis especially K_2O are extremely low
- (c) ferrous iron greatly exceeds ferric iron except in samples containing epidote.

The plots of the average chemical composition (Table 7) for the amphibolites in Uwet area (Figure 29 and Figure 31) show that they clearly fall into separate fields thus indicating their derivation from different progenitors. The banded amphibolite plots in the field of igneous rocks in all cases and is therefore interpreted as an ortho-amphibolite. On the other hand, the homogenous amphibolite plots in the sedimentary field in all cases and is therefore interpreted as a para-amphibolite.

The para-amphibolite has potash in excess of soda and may have been derived from a calcareous argillaceous sediment. It neither plots in the field of greywacke in the wt. % total iron as Fe_2O_3 against wt. % MgO diagram (Figure 32) nor falls into the field of the Franciscan greywacke. However, in the ACF diagram (Figure 31) it plots in the field of greywacke but very close to carbonate-rich shale. It is possible that the para-amphibolite is a product of metamorphism of a calcareous argillaceous rock. The rock contains secondary calcite and epidote.



- 1-- Contoured field for 76 greywackes analyses.
- 2-- The contours have been drawn at 1, 2 and 5 analyses per 0.25 % x 0.25 % square.
- Uwet area (Numbered are analysed samples - table 7).

Fig. 32 Plot of wt. % total Fe as Fe_2O_3 against wt. % MgO for rocks of Uwet area.

However, the homogeneity of the amphibolite is an evidence that it could as well have been derived from a mafic igneous rock. The geochemical data is inconclusive as can be observed in the plots of the homogeneous amphibolite in variation diagram (Figure 31). The plot in the field of greywacke, in particular, has an ambiguous meaning since a granodiorite could also plot in a similar field. Evans (pers. comm.) is of the opinion that the homogeneity of the amphibolite is an evidence of its igneous origin.

The banded amphibolite (ortho-amphibolite) plots in the alkalic field (Figure 33) on an SiO_2 Vs $(\text{Na}_2\text{O} + \text{K}_2\text{O})$ diagram of Macdonald and Katsura (1964). It has a Rb/Sr ratio of 0.10 (less than 0.12) which satisfies one of Van de Kamp's (1968) conditions for an ortho-amphibolite. It lies in the calc-alkaline field in the AFM diagram (Figure 34). The normative calculation (Table 9) shows that the banded amphibolite has nepheline and olivine in the norm. These parameters indicate that the ortho-amphibolite has an alkaline affinity. From the chemical analysis (Table 7) it is observed that the banded amphibolite has a very high content of alumina (19.30 wt. %).

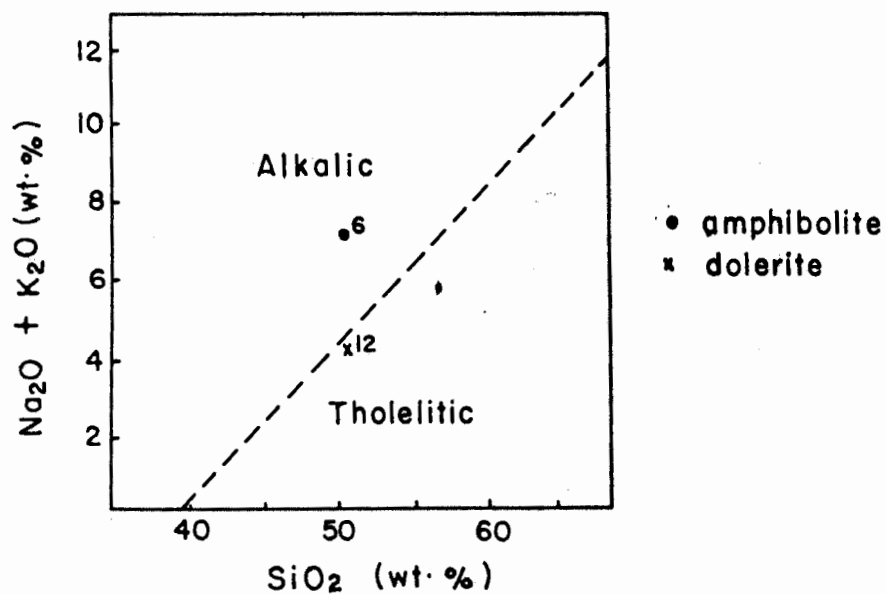


Fig. 33 Alkalis - silica diagram for Uwet dolerite and banded amphibolite (After MacDonald and Katcura 1964).

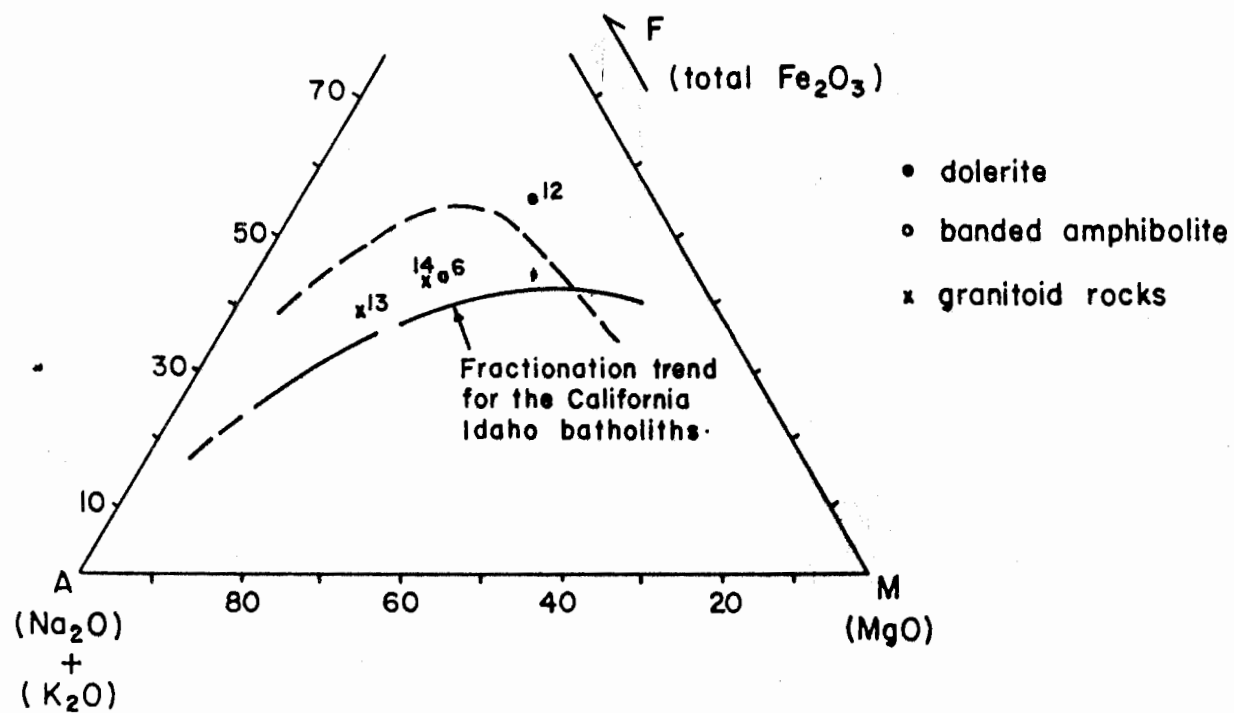


Fig. 34 AFM variation diagram for the rocks of Uwet area.
 (The broken line separates the calc-alkaline field
 from the tholeiitic field).

Wilkinson (1967) has shown that high -alumina basaltic magma is differentiated from other magmas by an alumina content in excess of 17%. Such magmas are intermediate between tholeiite and alkali olivine basalts (Kuno 1960) but range from alkali basalt through olivine basalt to olivine tholeiite (Ringwood 1975). The parent magma of the ortho-amphibolite is therefore a high alumina basaltic magma but closer to the alkali olivine basalt than the olivine tholeiite since there is no hypersthene in the norm. Such magma (high-alumina alkali olivine basalt) can be generated at a depth of 30-70 kilometers in the upper mantle by 5 to 10 percent degree of partial melting of mantle peridotite (Green and Ringwood 1967). Differentiation of olivine tholeiitic magma could also give rise to the parent magma of the banded amphibolite.

The ortho-amphibolite plots in the field of continental basalt in the $\text{TiO}_2\text{-P}_2\text{O}_5\text{-K}_2\text{O}$ diagram (Figure 35) of Pearce et al. (1975) and this is consistent with the world-wide occurrence of such basaltic rock (Kuno 1960; Wilkinson 1967). This shows that the Uwet ortho-amphibolite was emplaced in a continental environment. This is consistent with the ensialic nature of the Nigerian basement complex which is a part of the Pan-African mobile belts (Kroner 1977; Martin and Porada 1977). Truswell and Cope (1963), McCurry (1970), and Hubbard (1975)

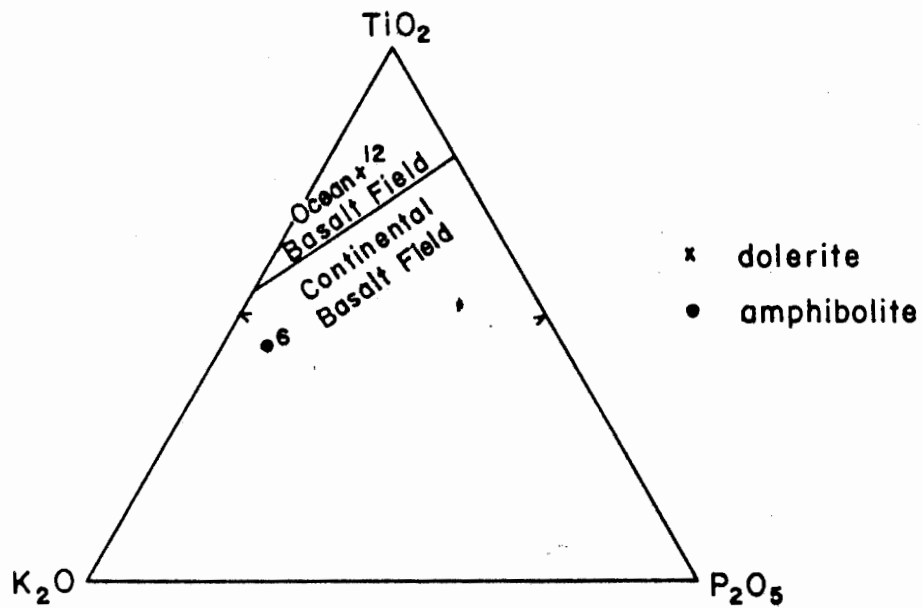


Fig. 35 Plot of Uwet dolerite and banded amphibolite on TiO_2 - K_2O - P_2O_5 diagram. (After Pearce et al., 1975).

have shown that the Nigerian 'schist belt' both in southwest and northwest Nigeria is associated with a series of fundamental and long-lived lineaments and major faults that have existed since the Precambrian times. Wright (1976) has shown that these ancient but still active lineaments probably extend across the continent into the oceanic areas as major fracture zones (Romanche and Chain fractures). Similarly, Grant (1970) and Leblanc (1976) have shown that there existed a late Proterozoic ocean and island-arc environment along the Pan African Pharusian-Dahomeyan belt at the eastern margin of the West African craton. It is most likely that the parent magma of the metabasalt of Uwet area reached the crust through these faults and lineaments.

The banded nature of the ortho-amphibolite may be attributed to differentiation which occurred during high-grade metamorphism of the area. This is consistent with the observation of Bowes and Park (1966), Evans and Leake (1960), O'Hara (1961) and Levenson and Seyfert (1969, p. 399) who attributed such bands in amphibolites to metamorphic differentiation or metasomatism or both and who have considered them unrelated to any original feature of the rock and of no stratigraphic significance.

Nevertheless, the possibility that the basaltic magma was intruded into or mixed with sedimentary rock cannot be ruled

out. This possibly gave the rock a mixed volcano-sedimentary origin and imposed both the strongly banded fabric and a mineralogy which is indicative of upper amphibolite facies conditions (cf. Annor and Freeth 1981, p. 35). This is more so as it has been shown that the onset of partial melting in most metamorphic terrains is inhibited by scarcity of water (Watson 1973, p. 452).

GNEISSES:

A plot of the average chemical composition of the gneisses (Table 7) on the ACF diagram (Figure 31) after Winkler (1967) shows that all of them plot in the field of sedimentary rocks (shales and greywackes). Some samples of the kyanite gneiss plot in the field of aluminium-rich clays and shales on the ACF diagram. This is consistent with the mineralogy which shows the occurrence of kyanite. The presence of this aluminium-excess mineral is a reflection of the aluminium-excess nature of the parent sedimentary rock.

However, when the average chemical composition of the gneisses is plotted on the Fe_2O_3 Vs. MgO diagram (Figure 32), all the analysed samples but one (kyanite gneiss) fell on the contoured field of greywacke. This is similar to the plot on the SiO_2 Vs. CaO diagram (Figure 30) where the gneisses except one plot on the field of Franciscan greywackes of Brown et al.

(1979). The gneisses plot in the field of eugeosynclinal sand-stones of Middleton (1960) on a K_2O against Na_2O diagram (Figure 36).

The consistency of these plottings coupled with the mineralogy of the gneisses (for example, the occurrence of kyanite in the kyanite gneiss) indicate that the gneisses may not be metamorphosed igneous rocks but metamorphosed sedimentary rocks. This is consistent with the origin of gneisses reported in parts of Nigeria. Rahaman (1978, p. 45) after comparing the chemical data of gneisses from parts of southwestern Nigeria arrived at an inconclusive geochemical evidence as regards their progenitors. According to him, the geochemical evidence shows the gneisses are compositionally similar to greywackes and shales and also to rocks in the diorite-monzonite range. Rahaman (1978) argued that the discriminant between gneisses of igneous and sedimentary origin is the structural relationship of the gneisses to the surrounding rocks since gneisses of average granodioritic composition would also fit into the data for an isochemically metamorphosed greywacke. However, based on the interbanding, on a megascopic scale, of his gneisses with quartzites and lenses of calc-silicate rocks, Rahaman (1978) concluded that the gneisses are of sedimentary origin. Freeth (1971) and Burke et al. (1972) had earlier shown that the

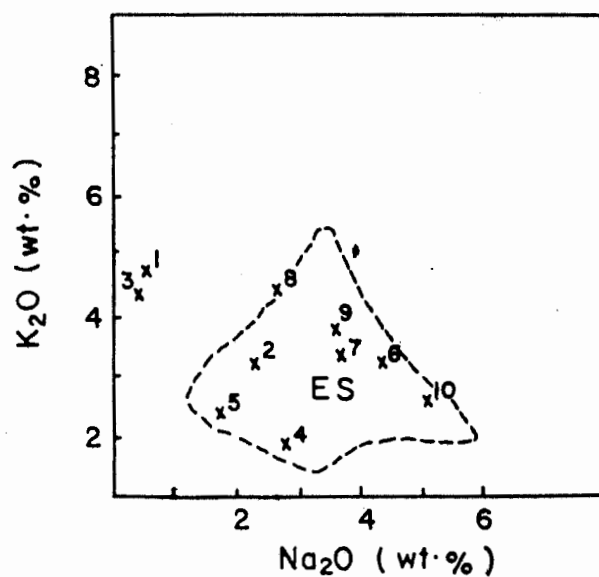


Fig. 36 Plot of the Uwet metasediments on K_2O Vs Na_2O diagram. E·S = eugeosynclinal sandstones field of Middleton (1960).

Ibadan banded gneiss was derived from greywacke and a greywacke-shale sequence respectively.

The chemical data for Uwet gneisses when compared with the granodiorite and greywackes reported in the literature (see Table 10) indicate that the ratio of the Na_2O to K_2O corresponds to those of the shale-greywacke sequence (Pettijohn 1957). The variation of this ratio within the same type of gneiss is an evidence of facies change during sedimentary deposition in the area. The high-alumina content of the gneisses (greater than 13 wt. %) in general and that of the kyanite gneiss in particular (greater than 19 wt. %) and the mineralogy of the gneisses strongly support the sedimentary nature of their progenitors. Their composition compares well with that of average greywacke given by Pettijohn (1975) (see Table 10). They are also interbanded on a megascopic scale with quartzite and calc-silicate rocks.

DOLERITE:

On an SiO_2 Vs. $(\text{Na}_2\text{O} + \text{K}_2\text{O})$ diagram (Figure 33) the dolerite plots in the tholeiitic field. It plots however, very close to the alkalic-tholeiitic boundary an evidence of its enrichment in alkalis. The dolerite plots in the tholeiitic field in the AFM diagram (Figure 34). On a TiO_2 - K_2O - P_2O_5 diagram of Pearce et al. (1975) the dolerite plots

in the field of oceanic basalt. The CIPW normative calculation shows that the dolerite has both olivine and hypersthene in the norm (Table 9) and according to Yoder and Tilley (1962) such magmas (tholeiitic) differentiate towards silica enrichment and plot on the right-hand corner of the critical plane of silica undersaturation of the normative basalt tetrahedron. The Uwet dolerite was therefore derived from an olivine tholeiitic magma.

The sugimura index (Θ) given by $\Theta = \frac{\text{SiO}_2 - 47 \times (\text{Na}_2\text{O} + \text{K}_2\text{O})}{\text{Al}_2\text{O}_3}$ (where SiO_2 is in wt.% and the other oxides are in molecular proportions) was calculated to determine the level of magma emplacement (see Sugimura 1968). Naqvi and Hussain (1973) have shown that the higher the value of Θ , the lower is the depth of magma generation. The Uwet dolerite shows Θ value of 27 and this indicates that it was possibly emplaced in a continental crust exceeding 30km in thickness. It has a value consistent with modern continental tholeiites. Oceanic tholeiites have Θ values greater than 36.

Green and Ringwood (1967) and Ringwood (1975) found that at a fairly high degree of partial melting of pyrolite at 13.5 kbar a parental olivine magma is formed. According to them, 25% partial melting of mantle peridotite accompanied by the segregation of the magma at a depth between 35 and 70 kilometers will generate an olivine tholeiitic magma.