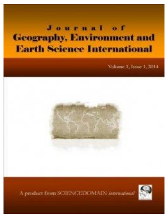

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The Geology and Structural Evolution of the Aningeje Metasediment in the Lower Part of Oban Massif, South-Eastern Nigeria

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Authors' contributions

This work was carried out in collaboration between both authors. Author PSM designed the study, wrote the protocol, and wrote the first draft of the manuscript. Author PSM managed the literature searches, analyses of the study performed the spectroscopy analysis and author NUE managed the experimental process and identified the species of plant. Both authors read and approved the final manuscript.

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ABSTRACT

The field mapping carried out in the study area was aimed at establishing the local geology of the area, which include the identification of rocks and minerals, and the reconstruction of the petrogenesis and structural evolution of the rocks in the area. Six representative rock samples from twenty two sample locations were selected for thin section petrographic analysis. The results revealed that the area is underlain dominantly by schist with pockets of granite gneiss, quartz-biotite gneiss, quartzite, pegmatite and amphibolite emplaced within the country rock (schist). The schist exhibits alternation of dark and white bands with foliation planes, and trending in the NE-SW direction. The quartz veins are leucocratic, whereas pegmatite contains porphyroblastic texture with the presence of leucocratic minerals (plagioclase). Certain index minerals revealed from the

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petrographic studies are; quartz, biotite, hornblende, microcline, muscovite, garnet, zircon, sphene, plagioclase and other accessories. These minerals suggested that the area was subjected to Barrovian sequence metamorphism of the amphibolite facies. Structural elements such as joints, fractures, foliations and veins show series of deformational episodes that affected the area, and the major NE-SW trend of the structures suggested Pan African event (600±150 Ma). Aningeje is endowed economically with valuable minerals such as quartz, mica, feldspar and other accessories. The rocks in the area are highly weathered, fractured and jointed. This provides a greater potential for ground water in the area.

Keywords: Petrography; quartz; rocks; metamorphism; minerals.

1. INTRODUCTION

The study area is located at Aningeje Community, within Kwa Falls Tourist Centre, north-east of Calabar, in Akamkpa Local Government area, Cross River State, Nigeria. It covers an area of about 45sq.km, and located between latitude 5º08'N and 5º11.5'N and longitude 8º29.7'E and 8º34.9'E. The area lies southeast of the Oban Massif (Fig. 1) and about 3km away from the contact between the sedimentary terrain of the Calabar Flank and the basement of the Oban Massif. Aningeje Town, where the study area is situated is bounded in the north by Ndingane Town, west by Okoroba, east by Ekong Anaku and south by Mfamosing, and Abati in the south-west. Kwa Falls, the Tourist Centre falls within Aningeje Town towards the Great Kwa River. Several workers have studied extensively on the basement rocks in Oban Massif, including the exposures at Kwa Falls area in Aningeje. The common basement rocks which have been reported in the area are banded schist, amphibolite, pegmatite and gneiss. The Nigerian basement rocks have been studied and classified by various workers based on lithology and petrography [1-3]. Based on petrological features, the Nigerian basement complex has been classified into four groups by [4]. Based on lithology, four major rock types are identified by [5]. They include: (i) Migmatite gneiss complex which comprises of biotite and biotite-hornblende gneisses, quarzites and paraschists, etc. (ii). Older granite, which comprises of rocks varying in composition from granodiorite to granites. (iii). Unmetamorphosed dolerite dykes believed to be the youngest; and (iv). Charnockitic rocks.

The essence of the field mapping was to identify the various rock types, minerals and structural features present in the area. The various rock types in the area concentrate valuable minerals of different types with high economic potentials. Understanding the geologic history of the area will help to reconstruct the provenance of sediments deposited in the adjacent sea/beach by the Great Kwa River since the Oban Massif serves as one of the sources of sediments feeding the offshore eastern part of the Niger Delta. The structural styles (presence of fractures, joints, and faults) in the area will increase the potential for groundwater exploration. The streams are highly polluted by the presence of the abundant minerals weathered from the rocks. Therefore, ground-water will be the safest source of potable water for the local community.

1.1 Location and Geology of Study Area

The Aningeje metasediments form part of the Oban Massif basement complex in the south-eastern Nigeria. The Oban Massif lies between longitudes 8º00´E and 8º55´E and latitudes 5º00´N and 5º45´N covering an area of about 8,740 km_2 [6], Fig. 1. It is located in the western part of the Cameroun Mountain and occurred in conjunction with the Obudu Plateau as an extension of the mountain into Nigeria. They form great spurs protruding into the Cross river plains of Southeastern Nigeria [7-11]. The basements are overlain by Cretaceous sediments of the Calabar Flank in the south and west but separated by a Cretaceous sediment filled graben or Mamfe rift (Embayment) in the north [9,11].

The Precambrian basement rocks of the Oban Massif are composed of phyllites, schists, gneisses, granulites and migmatites intruded by rocks of granitic, mafic and ultramafic composition, and range in age from Neo Archaean to Pan-African [12,10,13]. A dolerite in Obudu yielded 40Ar/39Ar plateau age of 140±0.7Ma [14]. The rocks exposed at Obudu Plateau are dominantly gneisses with several igneous intrusives [15].

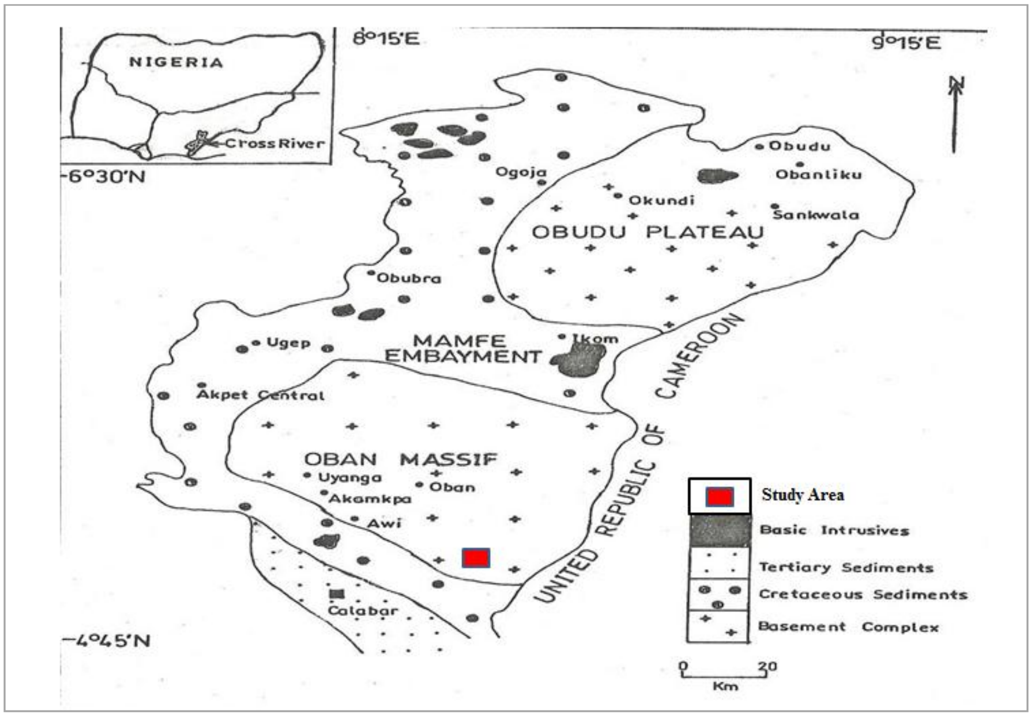

Fig. 1. Map of study area showing locations of crystalline basement complex in cross river state

The gneisses are migmatite gneiss, pyroxene gneiss, biotite granite gneiss, garnet hornblende gneiss and garnet sillimanite gneiss. The schist enclaves are very limited, while phyllites have not been reported in this environment yet [15]. The Oban Massif is dominated by phillites and schist, especially in the western part; the eastern part is dominated by migmatite gneiss and granite gneiss [15].

The Oban Massif basement has undergone polyphase deformation and polymetamorphism and several generations of folding, faulting, shearing and fracturing [16,14]. The dominant trend of the structural features comprising of planar and linear types is N-S to NE-SW (0-30º). Minor trends in the NW-SE and E-W also occurred and have been interpreted as relicts of pre-Pan African deformation episodes [2,16], [14,15].

2. MATERIALS AND METHODS

Six (6) representative fresh rock samples were selected from a total of twenty-two (22) samples collected during the field mapping for laboratory analysis. Thin sections of the rocks were prepared and studied using petrographic microscope at the geochemistry laboratory of the University of Calabar, Nigeria. The mapping was aimed at field identification of the different rock types, their field relation and structures, mineralogy, measurement of structures and proper description of the rocks which will serve to aid the reconstruction of the geology of the area. The various rock types encountered at the various locations were mapped and samples collected. Photographs were taken for the various rock types and geologic structures. Traverses along roads, bush tracts and footpaths were done using GPS (Global Positioning System). The GPS was used to take coordinates of sample points and also to measure distances and elevations. Gridding of the base map was done to determine the direction of the mapping exercise. Megascopic identification of the rocks was carried out in the field and tentative names were given until the final laboratory microscopic analysis was done.

3. RESULTS AND DISCUSSION

3.1 Petrology, Petrography and Field Relation of the Rocks

The mapped area consists of the Precambrian basement complex of the Oban Massif. The basement rocks occurred throughout the entire study area exposed majorly along the river channel (the Great Kwa River) and other parts of Aningeje. The dominant rock in the area is metasedimentary schist with other igneous intrusives (pegmatitite veins, dolerite) occurring as veins, dikes and sills. The schist occurs dominantly towards the western part of Aningeje, whereas outcrops of gneiss are more prominent towards the east.

The mapped area, Aningeje, has different types of metamorphic rocks (Fig. 2). They include metamorphosed pelitic schists, the dominant; gneisses, and amphibolite and quartzite.

3.2 Gneisses

The major types of gneisses encountered in the area are: biotite-gneiss, granite-gneiss and biotite-hornblende gneiss. They are medium to coarse grained and observed to have undergone polyphase metamorphism shown by their multiple deformation patterns, structural imperfections such as fractures and joints. The gneisses show well developed planar orientations whose fabrics are formed by variation in grain size. In the Oban Massif, the gneisses are varied [8]; [17]. Banding is not common and they are restricted to the eastern and western part of Aningeje and towards Okoroba. They are dissected by quartzo-feldspathic veins and dykes.

3.2.1 Biotite gneiss

This rock is dark coloured and relatively heavy in hand specimen. They are medium to coarse grained Fig. 3). Mineralogical composition of the rock include; quartz, biotite, labradorite and hornblende. Biotite, the dark brown mineral occurred as irregular foliated masses with hexagonal crystal outline. It has the highest modal composition followed by quartz and labradorite. Biotite belongs to the class of hydrated alumino-silicates (mica) likewise muscovite.

3.2.2 Petrography

Under transmitted light, the representative sample displays mineralogical association. The quartz is observed to lack cleavage, has low relief, colourless or faintly coloured. It has low interference colour, lacks alteration, no twinning, with parallel extinction. The biotite was recognized by their brown colour without preferred orientation of its platy minerals (Fig. 5). It shows oblique extinction with perfect cleavage in one direction, and has the highest modal composition in the rock (Figs. 3 and 4).

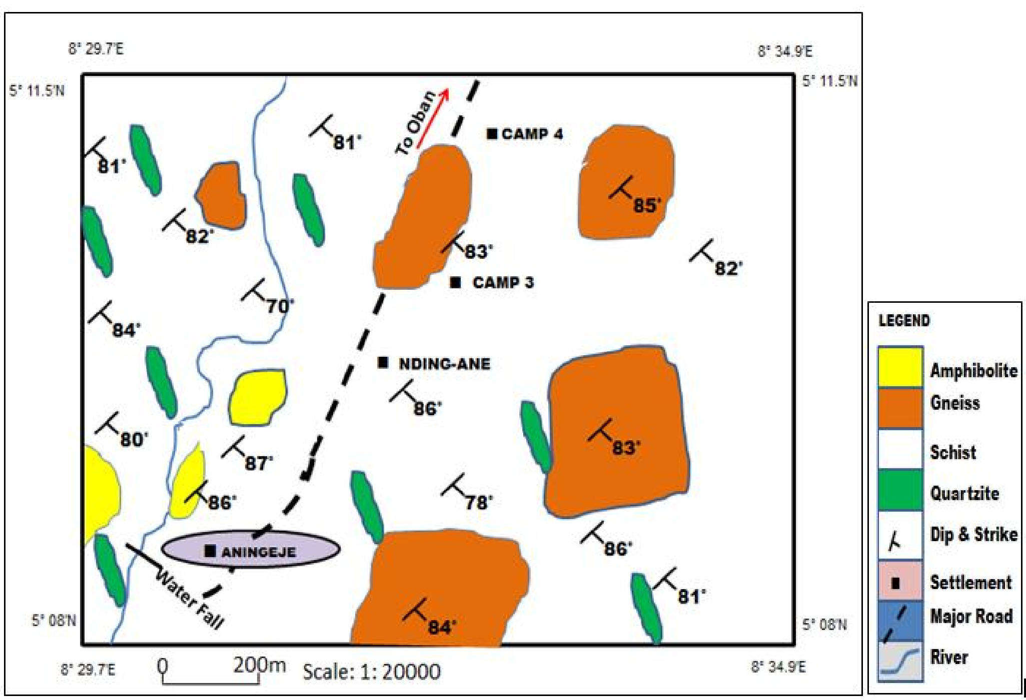

Fig. 2. Geologic map of Aningeje and its environments

Microcline is observed to be colourless and cloudy due to alteration. It is clearly seen by its perthitic texture and polysynthetic twinning. It has low relief and occurs as anhedral crystals. Zircon is identified with its pale brown colour with short prismatic habit. It has a very high relief with parallel extinction and stronger birefringence. Labradorite is identified with its 30º extinction angle, which corresponds to An_{50}.

3.2.3 Field relation

The rock is weathered and exposed by stream channel cutting through it. It is highly fractured, banded, folded and foliated. There is impregnation of quartz veins along planar surfaces and mineral lineations.

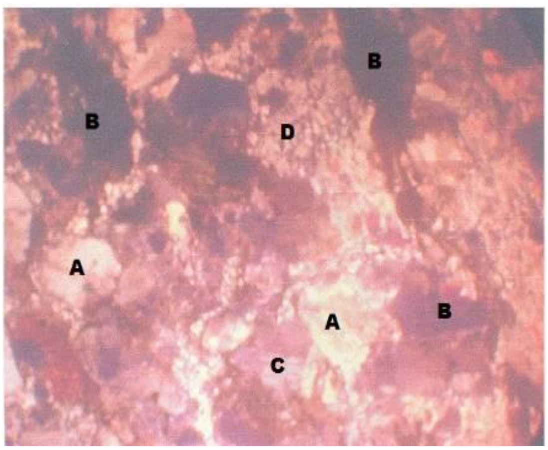

Fig. 3. Photomicrograph of biotite-gneiss (A=Quartz, B= Biotite, C= Labradorite, D = Hornblende)

3.3 Granite-Gneiss

The granite gneiss of Aningeje is characterized by medium to coarse grained texture. The basement complex in the area has been affected by deep-seated high grade regional metamorphism evidenced by cataclastic deformation which produced multiple features found in the rock (Fig. 5).

3.3.1 Petrography

From hand specimen the representative sample (Fig. 5) is medium to coarse grained with porphyroblastic texture and highly foliated. The mineral assemblage as shown in the photomicrograph on Fig. 5 was studied in thin section. The modal composition (Fig. 6) of the rock consists of quartz in highest composition. The quartz is colourless, lack cleavage and twinning, has low interference colour, lacks alteration and has parallel extinction. The relief is low and has birefringence of 0.009 showing first order grey. The presence of biotite is recognized by its brownish-yellow colour. It shows pleochroism from yellow to dark brown. It has a perfect cleavage with moderate relief and shows straight extinction. The birefringence is 0.037. Microcline occurred as the greenish mineral, strongly pleochroic with a high relief, and oblique extinction (between 12º to about 30º). Twinning is common. The plagioclase feldspar seen in the thin section is labradorite with a composition of Ab_{59}, and An_{41}, indicating a medium grade metamorphism. Other components of the rock are accessory and opaque minerals.

3.3.2 Field relation

The representative sample was found to occur in close contact with quartz veins which are concordant with mineral alignment. The veins are believed to have occurred as a result of syndeformational process during the last orogenic episode because it is concordant with the trend of the foliation.

3.4 Schist

The schist in Aningeje contains biotite and quartz. Biotite (mica) is dominant. It is dark coloured, shows banding with its characteristic schistosity. It has igneous intrusive (pegmatite) which trend in the same direction (concordant) with the schist. The rock is highly weathered, fractured and foliated.

3.4.1 Quartz-biotite schist

The specimen sample is fine to medium grained in hand specimen with alterations of its micaceous streaks properly developed. The shiny flakes of mica (muscovite) were conspicuous enough to allow megascopic determination. Petrographic determination of its representative sample revealed the presence of quartz (Fig. 7). The minerals display the following optical properties when viewed under transmitted light: it is colourless, lack cleavage and not pleochroic, has low interference colour – with parallel extinction, a birefringence of of 0.009 showing first order grey. The muscovite in the sample displays a colourless to pale green hue. Pleochroism is weak; cleavage is in one direction with parallel extinction. It has a birefringence of 0.037 showing first order grey.

Biotite and quartz are dominant in the rock (Fig. 8). Biotite is identified with its characteristic dark colour in megascopic observation. In the slide it appears brown to brownish green in colour showing pleochroism from yellow to dark brown. It is speckled near extinction.

Hornblende observed in the thin section (Fig. 9) has tones of green, showing pleochroism from yellow to green. It has prismatic habit, cleavage at 56º and 124º. Relief is moderate to high with extinction angle of 12 to about 30º. It has moderate birefringence of 0.026 with maximum interference colours of second order. The garnet present is pale brown in colour. It has very high relief, euhedral in shape, cleavage is absent and fractures common. Pleochroism present is colourless, oblique extinction, shows multiple twinning according to Albite law. Its composition was determined using the Michael Levy's Chart to be Ab_{64} An_{36} corresponding to labradorite. Quartz and biotite have the highest modal composition (Fig. 8).

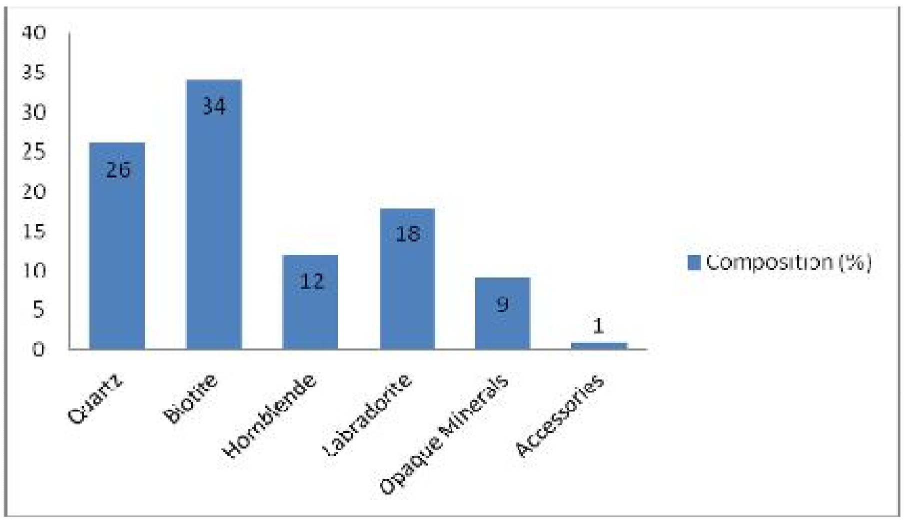

Fig. 4. Modal composition of Biotite-Gneiss

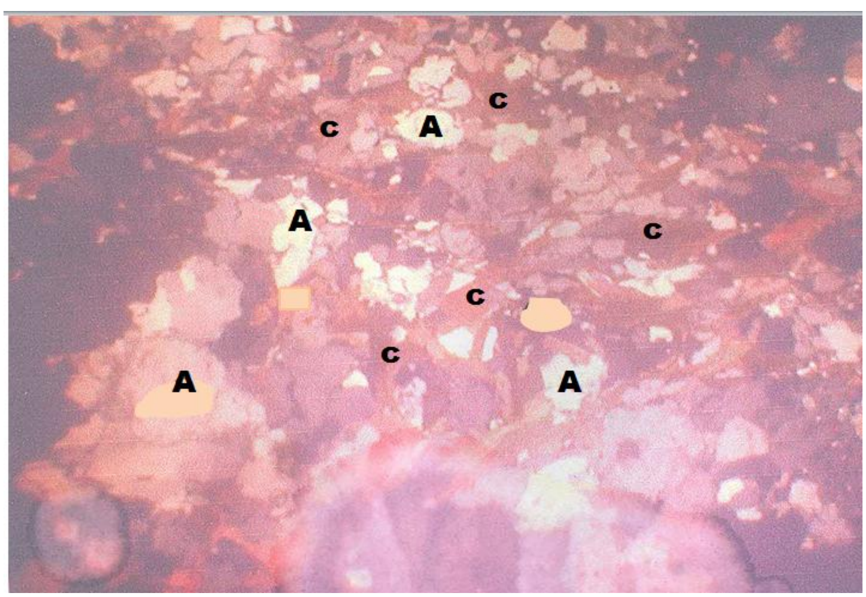

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Fig. 5. Photomicrograph of Biotite-gneiss (A= Quartz, B = Labradorite, C= Biotite,)

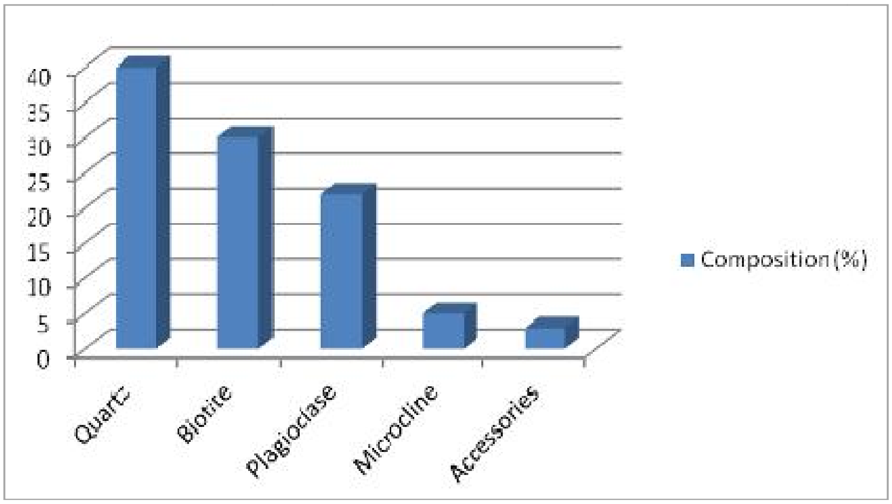

Fig. 6. Modal composition of granite-gneiss

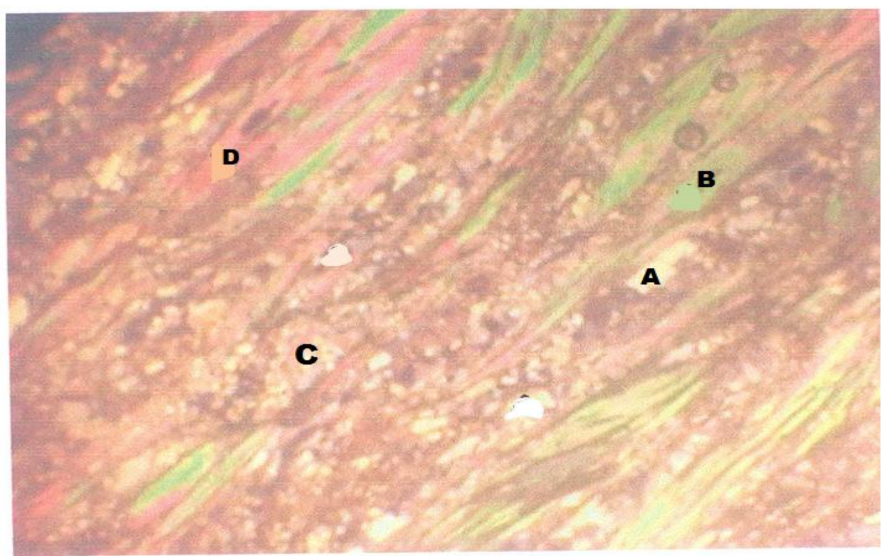

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Fig. 7. Photomicrograph of quartz-biotite schist (A=Quartz; B= Hornblende; C= Garnet; D= Biotite,)

3.4.2 Field relation

The rock (schist) in Aningeje is well exposed along the bank of the Great Kwa River. It displays banding – an alternation of dark and light bands. The light band is altered to reddish-brown in colour due to chemical weathering or contamination by lateritic soil. This is observed on exposure outside the river bank. The schist displays structural features such as lineation, foliation and fractures. Generally, the schist is strongly weathered and fresh exposures are scarce [11]. It shows strong schistosity and trends NE-SW. this confirms the Pan African event that affected the region about 600±150 Ma ago. According to [18], the schist belts represent a Proterozoic succession deformed during the Pan African orogeny.

As observed along the river channel, the schist is highly sculptured and fractured. Differential weathering of the schist accounted for series of waterfalls existing in the area. The schist in Aningeje occurred majorly in the western part of the area and is commonly intruded concordantly by quartz veins, quartzo-feldspathic and pegmatite bodies ranging in diameter from 30 cm to about 550 cm.

3.5 Amphibolite Petrography

Under thin section observation, the minerals identified are hornblende, biotite, quartz and plagioclase. Hornblende is the dominant mineral observed in the thin section (Fig. 9). Its modal composition is about 53% (Fig. 10). It is pleochroic, from white to green, elongated and prismatic. Cleavage is 56 and 124º with moderate to high relief. Extinction angle is 12 to about 30^0 and twinning is common. Biotite is recognized by its reddish-brown colour and cleavage lines more closely packed than in horneblende (Fig. 9). Its modal composition is 10% and present in small amount. Quartz is about 20%. Plagioclase is twinned with anorthite composition varying between An_{20-40}. It is colourless, has low relief and cleavage in three directions. Amphibolite in this area is of low grade metamorphic facies.

3.5.1 Field relation

Amphibolite was found in three locations in the northwestern part of Aningeje (Fig. 2). The rock is dark in colour and contains majorly ferromagnesian minerals of mafic origin. It occurs as pockets within the schist intruding discordantly into it. It is homogenous and restricted in occurrence. They are highly deformed and mineral lineation is not so pronounce as in the schist. It is medium grained, hard and more resistant to weathering than schist.

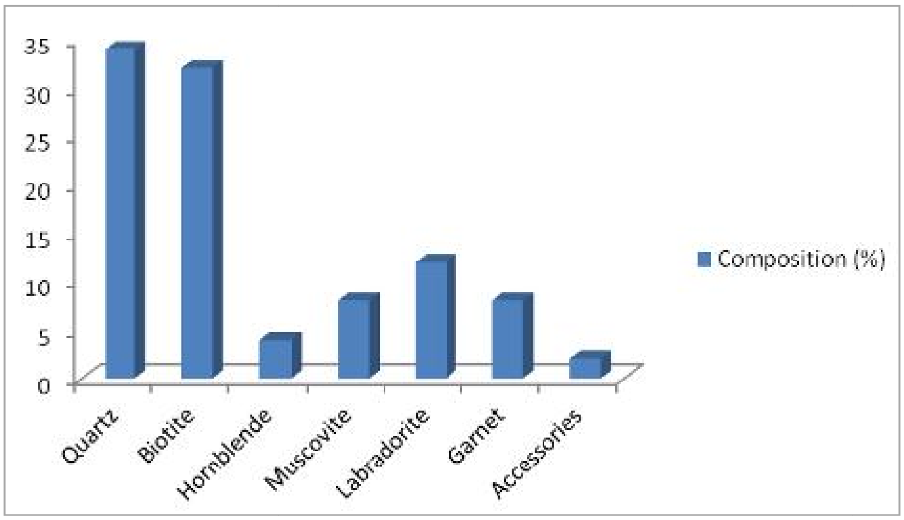
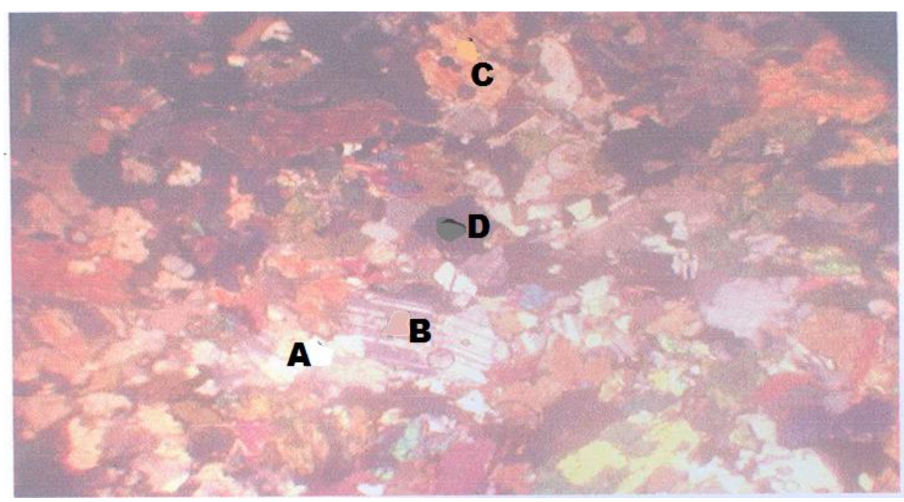


Fig. 8. Modal composition of quartz-biotite schist



Cpl, x35

Fig. 9. Photomicrograph of amphibolite (A=Quartz; B= Plagioclase; C= Hornblende; D= Biotite)

3.5.2 Quartzite

Quartzite occurs majorly in the northeastern part of Aningeje (Fig. 2). They are very resistant to both chemical and physical weathering. It occurs as boulders scattered all over the area.

3.5.3 Pegmatite

They are coarse grained igneous rocks with phenocrysts of about 30 cm in length. Pegmatite is associated with the late stages of crystallization of magma. In Aningeje, megascopic observation of the rock shows large crystals of quartz and pinkish coloured minerals possibly of plagioclase feldspar. The pegmatite veins range in diameter from about 30 cm to 550 cm intruding concordantly into the foliation planes of the schist body.

3.6 Structural Geology/Evolution of the Study Area

Several structural elements occurred in the rocks of the study area. Presences of joints and fractures have been observed in rocks in Aningeje (Fig. 15). According to [4,19,5,18,20] the basement complex of Nigeria is believed to have undergone polyphase deformations during the Precambrian. This deformation is believed to be prior or contemporaneous with the metamorphism. The latest and most penetrative episode occurred during the Pan African orogeny (600±150 Ma), [18]. This orogeny is as a result of the continental collision between the West African craton and the East African block. As a result of the polyphase deformations, complex structures are associated with the Nigerian basement. These structures display different orientations depending on the deformation episode producing them. The structural elements include; fractures, joints, foliations, lineation and folds. The dominant structural features encountered in Aningeje are foliation, fractures and joints. The schists were deformed dominantly by brittle fracturing, whereas the gneisses and granitic rocks were deformed dominantly by ductile processes.

3.6.1 Foliation

Foliation is a penetrative planar structure in the rock which may be defined by fabric, compositional layering or pervasive fracture. According to [11], the N-S to NE-SW trending foliation is conspicuous and recognizable in most rocks in the area and is best developed at Kwa Falls area. At Kwa Falls the foliation is steeply dipping (82-90º) towards 290-320º [11]. The foliation is parallel to the metasedimentary bedding which is conspicuously exposed in the area. The attitudes (strike/dip) of the foliations were measured and tabulated as shown in tables 1 to 6. These data were used to plot rose diagrams (Figs. 11 and 14) and histograms (Figs. 11, 12).

3.6.2 Joint and factures

Joint are fractures within a rock unit but there has been no relative movement of rocks along the fracture. Joints are caused by the vertical movement caused by earthquake waves, and the cooling of igneous rocks. The rocks at Aningeje are highly fractured and jointed (Fig. 15). The fractures as observed in the field are oriented perpendicular to the foliation planes. They cut across the foliations.

The fracture pattern and joints in the mapped area suggests that the area suffered brittle or cataclastic deformation. The trend of the fracture is variable depending on the deformational episodes that produced them. Fractures trending N-S to NE-SW (0-30º) have been attributed to Pan African thermotectonic event [14].

Table 1. Strike and dip values of foliation of gneisses

Strike	Dip	Strike	Dip	Strike	Dip
140	70E	088	70W	050	42E
015	80E	012	70W	014	76W
172	80E	068	62W	142	54W
140	82E	132	80E	174	40W
168	72E	112	65E	150	40W
110	84E	166	60W	013	40W
100	82E	080	73W	010	50W
042	64E	090	80E	022	62W
042	62E	120	86E	022	48W
082	68E	082	80W	020	50W

All other structures are believed to be the product of pre-Pan African deformation and both have been recognized in the Oban Massif and Obudu Plateau [11]. Tables 1 to 6b below show a record of values of measured attitude. A plot using the strike values produced a rose diagram showing a NE/SW trend of the fractures/joints suggesting a Pan African age of the rocks typical of the Nigerian basement [11]. From the histogram (Figs. 12 and 15) the dominant trend occurs in the ranges of 31-60º, 91-120º and 151-180º (Tables 2, 4a, 4b, 6a and 6b).

Table 2. Frequency distribution of strike amount and direction of gneisses

Class Interval	Frequency	Percentage	Width
1 – 30	8	27	1
31 – 60	3	10	2
61 – 90	6	20	3
91 – 120	4	13	4
121 – 150	5	17	5
151 - 180	4	13	6

3.7 Geologic History

The basement complex of the area which comprise of majorly metamorphic rocks include; schist (the country rock), gneisses and amphibolite. Other rocks of igneous origin that occur as veins include pegmatite and quartzo-feldspathic veins. Petrographic studies of the representative samples revealed the presence of certain minerals such as biotite, quartz and garnet, used in the classification of the grade of metamorphism. The minerals range in size from fine to medium grained in the schist, amphibolite and the gneisses. Very coarse grain is observed in the pegmatite. Structural elements observed in the rocks include foliation, lineation, folds, joints and fractures. The trend of these structures is majorly in the NE-SW direction indicating a Pan African age for the rocks in the area. These rocks which formed part of the Oban Massif and the Nigerian Basement were affected by the same tectonothermal event. According to [19,5,21] the metamorphism of the Nigerian basement was of the Barrovian or Buchan type, although [20] described a typical Abukuma- type mineral assemblage in Okene area Southeastern Nigeria. The Nigerian basement has undergone polymetamorphism and the highest grade of metamorphism reached was the upper amphibolite facies. The Aningeje schist belt falls within the amphibolite facies. This is confirmed by the presence of certain minerals such as biotite, hornblende and garnet. The dominant rock in the area is schist occurring majorly towards the western part of Aningeje. It is the oldest rock in the area derived from the metamorphism of pelitic sedimentary rocks. The gneisses are of granitic origin which intruded into the country rock (schist). Amphibolite may have been derived from the metamorphism of mafic igneous rock of basaltic origin, possibly dolerite that intruded into the schist also.

Table 3. Strike and dip values of foliation of schist in Aningeje

Strike	Dip	Strike	Dip
090	89W	022	64W
090	70W	022	52W
024	88W	180	74W
024	78W	024	50W
016	60W	136	87E
018	50W	140	58E
038	52W	040	70W
160	30W	044	48W
140	40E	052	60E

Pegmatite observed in the area is structurally controlled in occurrence. They exist as veins in the foliation planes of the schist. They are igneous rocks formed at the later stage of crystallization and may be the youngest rock in the area according to the law of cross-cutting relationship. The various rock types encountered in the area include: schist, which is banded and widespread within Kwa Falls area and western part of Aningeje, with little or poor exposure towards the east. The banded schist trends NE-SW and is dated by Rb-Sr method to be 527±26 Ma for the dark portion, and 627±24 Ma for the light portion [18]. The width of the vein ranges from 2 cm to about 5 m. The pegmatite contains very coarse grained quartz, feldspars, mica and other minerals existing as accessories. There is an intergrowth or graphic texture between the quartz grains and the alkali feldspar. Other rock types are biotite-gneiss, amphibolite and quartzite. The gneisses are highly varied [8,9 [17]. They include biotite-garnet hornblende gneiss, kyanite gneiss, granite-gneiss, etc. The amphibolite, a metabasite, exists as pockets within the Kwa Falls area and towards Okoroba. It is dark in colour containing majorly hornblende. The quartzite, a monomineralic metamorphosed quartz exist as big lumps or boulders exposed at the surface, not in situ. It was never fragmented due to its high resistance to weathering. In terms of area extent and distribution of the various lithologic units, the gneiss existing as boulders occurred more on the eastern part of Aningeje than in the west, whereas the schist covers more than half of the entire area in a NE-SW direction. The quartzites are scattered in the north-eastern part of the area, probably they may have intruded the heavily weathered and eroded country rock as dykes or veins, or may result from the metamorphism of pockets of sandstone contained within the pre-metamorphosed shale. Amphibolite occurred within Kwa Falls area. The schist is highly fractured and differentially weathered creating the waterfalls.

3.7.1 Petrogenesis

Megascopic and microscopic studies of rocks from Aningeje revealed that the area has been affected by metamorphism. Petrographic studies confirmed the various rock types. [22] affirmed that petrographic observations are powerful tool for deciphering the basic aspects of metamorphic rock history. From the mineralogical composition of the rocks, we can establish that the gneisses were derived from the metamorphism of igneous rocks evidence by its high percentage of ferromagnesian mineral – hornblende. The schist is formed from a retrogressive phase of regional metamorphism in pelitic rocks. They are well foliated and have high degree of orientation of the micaceous content typical of pelitic schist. The quartzite was formed from the metamorphism of sandstone.

Table 4a. Frequency distribution of strike and dip amount of schist

Class interval	Frequency	Percentage	Width
1 – 30	7	39	1
31 – 60	4	22	2
61 – 90	2	11	3
91 – 120	-	-	4
121 – 150	3	17	5
151 - 180	2	11	6

Table 4b. Analysis of foliation measurement of schist in Aningeje

Quadrants	Percentage	Total foliation readings	Width	Quadrants	Percentage	Total foliation readings	Width
1 – 30	39	7	6	180 – 210	39	7	6
31 – 60	22	4	4	210 – 240	22	4	4
61 – 90	11	2	2	240 – 270	11	2	2
90 - 120	-	-	-	270 - 300	-	-	-
120 - 150	17	4	2	300 – 330	17	4	2
150 - 180	11	2	2	330 - 360	11	2	2

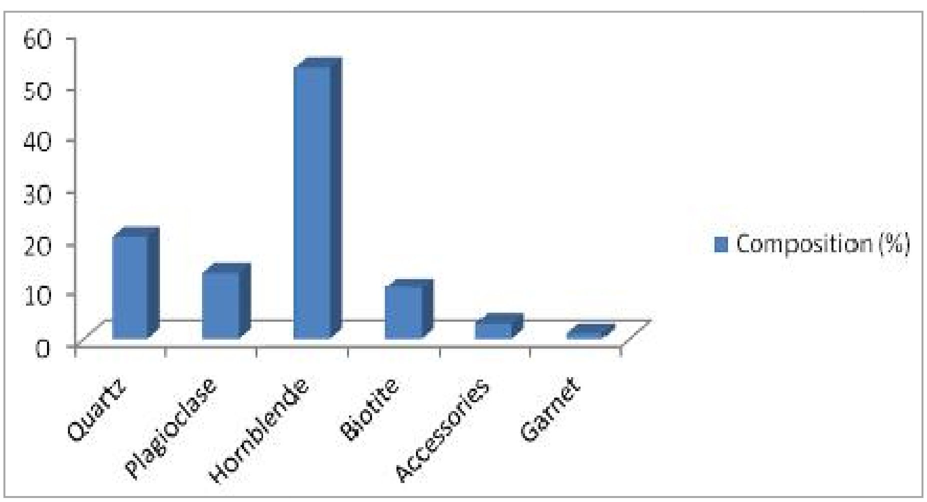


Fig. 10. Modal composition of Amphibolite

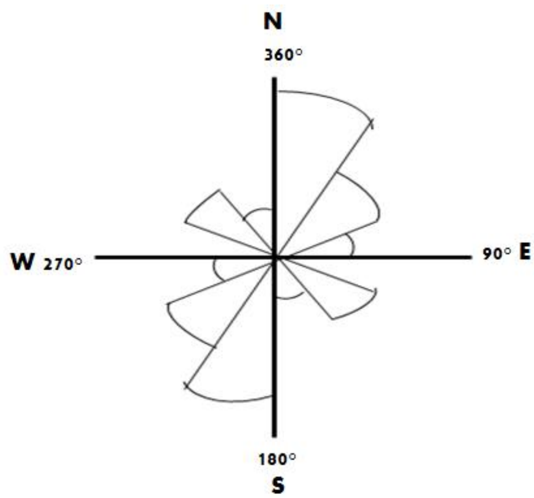


Fig. 11. Rose diagram for foliation of schist in Aningeje

3.7.2 Igneous petrology

The dominant igneous rock encountered in Aningeje is pegmatite which occurred majorly as veins. It is identified by its excessively coarse grained minerals of quartz, feldspar, mica and other accessories. The pegmatite veins intrude into the foliation planes of the schist trending in the same direction with the schist. It ranges in diameter from about 40 cm to 550 cm. Pegmatite criss-cross the metamorphic rocks of Oban Massif and are associated with low to medium and high grade metamorphic rocks [13].

3.8 Economic Geology of Aningeje

The mapped area possesses abundant valuable minerals which are of economic importance. The minerals are contained in the rocks and soils in the area. They include; quartz, biotite, muscovite (mica), plagioclase, sand, gravel, etc. They occur in association with the schist body, gneisses and the intrusive (pegmatite). These minerals have both engineering/construction and industrial importance. Quartz, for instance, is a good raw material for the production of all sort of glasses, abrasives, sand-papers, and for road construction. Mica minerals (biotite and muscovite) could be used in the manufacture of electrical insulators and as foil papers. Pegmatite is rich in feldspathic minerals used in the manufacture of porecelain, pottery ware for production of glasses on earthware and enameled bricks, and also as building materials. These minerals are fit for these purposes because they possess certain geological and physical properties such as strength, durability, ease of processing and quarrying. The gravels and sand occurred within the stream channel and the bank of the Great Kwa River.

3.9 Hydrogeological Potential

The hydrogeologic potentials of the study area involve all the geologic factors that control the occurrence of ground water, and also take into consideration the physical laws which describe mathematically the movement of ground water. Aningeje area belongs to the basement complex province of Cross River State, [23].

Table 5. Strike and dip values of fractures in rocks in Aningeje

Strike	Dip	Strike	Dip	Strike	Dip
050	10E	090	69E	022	088E
065	82E	088	82E	184	14E
150	82E	067	62E	138	85E
044	09E	038	60E	082	69E
074	68E	224	80W	074	80E
054	24W	082	58E		
038	69E	022	77E		
060	68E	064	90E		

The ground water occurrence in the basement complex is entirely dependent on the fractured and jointed areas, and also on the weathered overburden sediments. According to [23,24], recharge to the weathered zones and joint system have been greatly restricted where there is significant lateritic cover because of low permeability of the laterite.

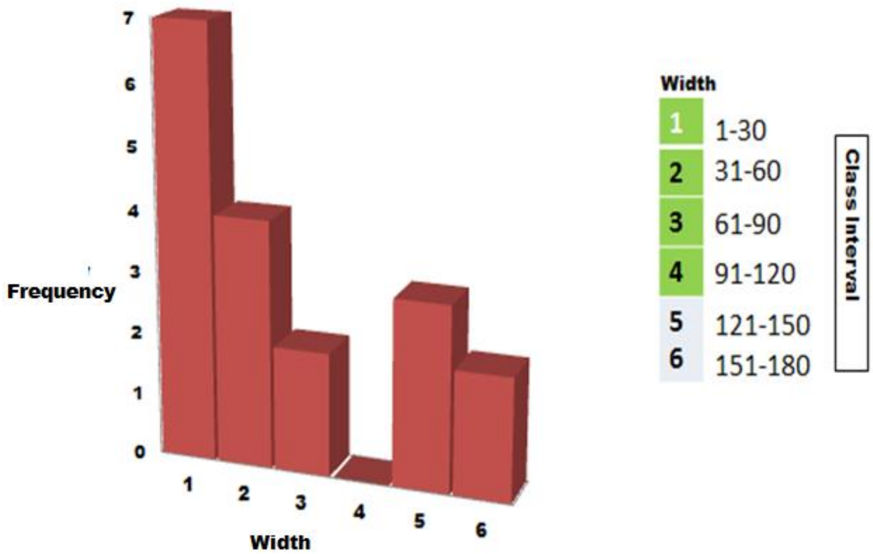


Fig. 12. Histogram for foliation of schist in Aningeje

Fig. 13. Joints and fractures in Aningeje

Table 6a. Frequency distribution of fractures, strike amount and direction

Class interval	Frequency	Percentage	Width
1 – 30	1	6	1
31 – 60	6	33	2
61 – 90	9	50	3
91 – 120	0	0	4
121 – 150	2	11	5
151 - 180	0	0	6

Table 6b. Analysis of foliation measurement of schist in Aningeje

Quadrants	Percentage	Total foliation readings	Width	Quadrants	Percentage	Total foliation readings	Width
1 – 30	8	7	2	180 – 210	8	4	2
31 – 60	30	4	4	210 – 240	30	9	4
61 – 90	43	2	6	240 – 270	43	15	6
90 - 120	-	-	-	270 - 300	-	-	-
120 - 150	19	2	3	300 – 330	19	5	3
150 - 180	-	-	-	330 - 360	-		

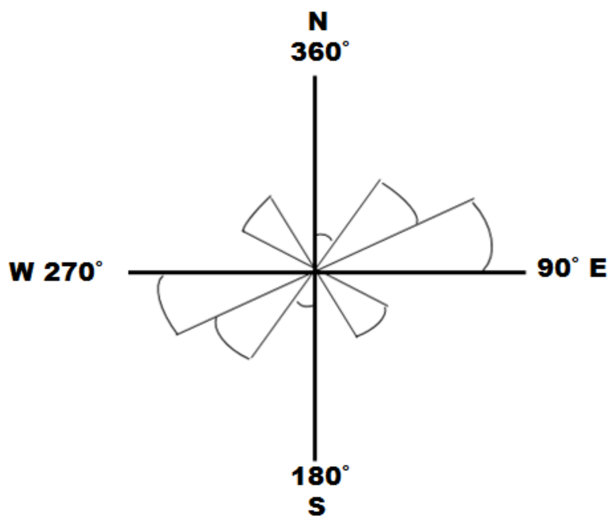


Fig. 14. Rose diagram for fracture of rocks in Aningeje

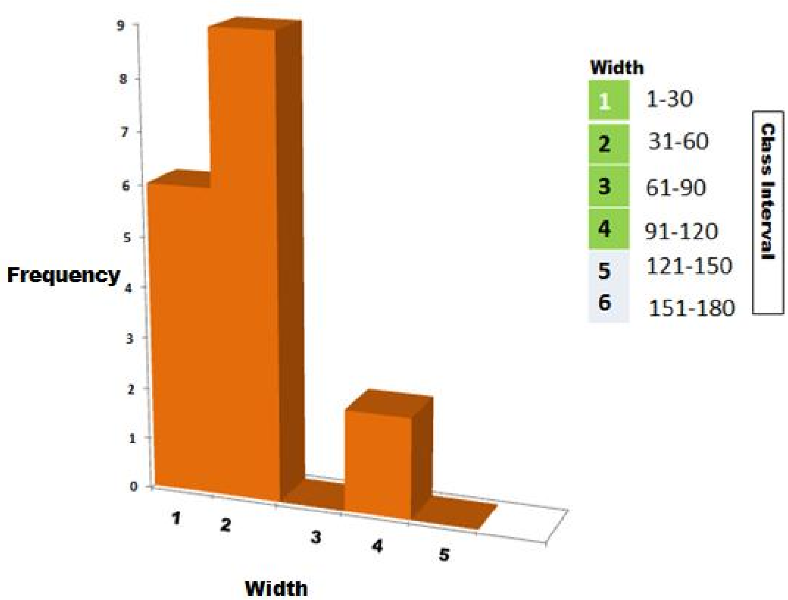


Fig. 15. Histogram for fracture of rocks in Aningeje

4. CONCLUSIONS

The metasediemntary schist in Aningeje in the south-eastern part of the Oban Massif has been studied. The schist occurs in alternation of white and dark bands. It occurred dominantly towards the western part of Aningeje within Kwa Falls, and exposed along the Great Kwa River. Differential weathering of the schist along the river channel created the waterfalls that form the major tourist attraction within the area and in Cross River State at large. The topographic differentials of the rocks and the river provide potential for hydro-electricity generation. The schist appears to be the oldest rock in the area base on field relation of other rocks. Other metamorphic and igneous bodies such as pegmatite, gneiss, amphibolite, quartzite and dolerite occurred as dikes, sills and veins. The concentration of the schist within the Great Kwa River axis may indicate that the area was structurally and geologically unstable, and would have been more susceptible to tectonic disturbances, thereby created a depression for the marine event that deposited the sediments (shale) that metamorphosed into schist. The dominant trend of the foliation as shown in the rose diagrams (Fig. 4b and 6b) is in the NE-SW direction suggesting a Pan African event. The abundance of gneiss in the eastern part of Aningeje suggests a more stable terrain with low weathering potential and rocks suitable for construction purposes. The tectonism, metamorphism and volcanic events produced the igneous intrusives and structural discontinuities in the basement. The fractures, joints and fissures in the area are imprints of brittle deformation of the rock. The western part of Aningeje toward Kwa Falls will have higher groundwater potential because of the high density of fractures and joints in the rock. The streams and the GKR will be highly polluted due to intense weathering of the schist within this zone. Generally, the basement rocks especially granite and gneiss are construction materials used for road building. There is a quarry site where this resources are been mined. The river in the area helps to transport weathered sediments to the sea, therefore forming the provenance for sediments deposited in the shallow offshore eastern Niger Delta Basin.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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