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The Geology, Petrography, and Economic Potential of Parts of Nassarawa-Eggon and Environs, North Central Nigeria

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ABSTRACT

Detailed geological mapping of the research area was carried out to update the previous information known about the geology of the study area on a scale of 1:12,500. Previous geologic research was carried out on smaller scales. The study area is located in Nassarawa-Eggon Local Government Area of Nassarawa State, North-Central, Nigeria, lying between Latitudes 8° 42’ 13” and 8° 45’ 00” N, and Longitudes 8° 30’ 00” and 8° 32’ 10” E. The new geologic map was produced to establish the relationship between different lithological units by mapping out distinct geologic boundaries, and delineating the general structural trend of associated geologic structures on a geologic map. Results from petrographic analysis of rock thin-sections obtained from the study area reveal the presence of Migmatite, Gneiss, Granite, Rhyolite, Quartzite and Dolerite. Associated geological structures observed include foliation, ptygmatic folds, dykes, veins and faults/joints. Rose plots indicate that the prevalent structural trends are in the NE-SW, NNE-SSW and N-S directions, which are peculiar to the Precambrian rocks of the Nigerian Basement Complex affected by the Pan-African Orogeny. The research area is enriched with economic mineral resources such as iron ore and amethyst, and the rocks are mostly quarried for engineering purposes.

1. INTRODUCTION

The study area consists of the Nigerian basement complex rocks which are well exposed in the central part of the study area, occurring as a chain of granitic hills stretching from the east to the west. These basement rocks have been affected by at least four major orogenic cycles; the Liberian (2,700 Ma), the Eburnean (2,000 Ma), the Kibaran (1,100 Ma), and the Pan-African (600 Ma) orogenic cycles [25]. These orogenies were characterized by intense deformation, isoclinal folding, regional metamorphism, migmatization, extensive granitization and gneissification, producing syn-tectonic granites and homogeneous gneisses [1]. The final stage of the last deformational cycle was characterized by the late tectonic emplacement of granites and granodiorites, and associated contact metamorphism [25]. These orogenic cycles were concluded by faulting and fracturing [7, 26] whose azimuths are depicted to trend in the NE-SW and NW-SE direction [3].

From aeromagnetic data estimated using the Peter's (half-slope) method from the Wamba Area of which the study area lies within, on a scale of 1;100,000, there were indications of the presence of two depth source models [3]. The deeper sources ranging in depth from 0.88km to 3.15km were most likely produced due to intra-basement bodies [3], possibly rhyolite and quartzite observed as small ridges in gneiss within the study area.

This study is centred on updating previous geologic information [2, 27] on a larger scale of 1: 12,500 by establishing the lithological units and delineating the geologic structures as found in the field [17, 23]. Furthermore, insight on the economic potential of the study would be discussed within this text.

2. LOCATION AND ACCESSIBILITY OF STUDY AREA

The study area lies within Wamba Sheet 210SW in Nassarawa State, North-Central Nigeria, between Latitudes 8^0 42’ 13” N and 8^0 45’ 00” N and Longitudes 8^0 30’ 00” E and 8^0 32’ 10” E. It covers an area of approximately 20 km^2. It is majorly accessible by the Akwanga to Nassarawa-Eggon road, and has several footpaths prevalent within the surveyed area. Notable nucleated settlements within the study area include Alogani North, Alogani Central, Tawa Galle, and Galle.

3. RELIEF AND DRAINAGE OF THE STUDY AREA

Most of the study area (particularly the central area), is a highland (between 200 - 300 metres), consisting mostly of an east-west trending hilly landscape. The highest elevation recorded is located at the north of the study area (close to Gidan Waya settlement), and is characterized by the rocks of the Nigerian Basement Complex (Gneiss and Granite).

At lower reliefs, a doleritic dyke was encountered adjacent to a Quartzite ridge. Outcrops of migmatite alongside gneiss, granite and lateritic cover were also observed at lower elevations towards the north (close to a present-day Fulani settlement), and on the south-side, (towards Tawa Galle settlement).

The few drainage channels observed exhibit the dendritic drainage pattern (Figure 1), which correspond to the structure and relief of the landscape. A dendritic drainage pattern is geomorphologically controlled i.e., controlled by the rock types and the nature of structures observed on these rocks [12, 14].

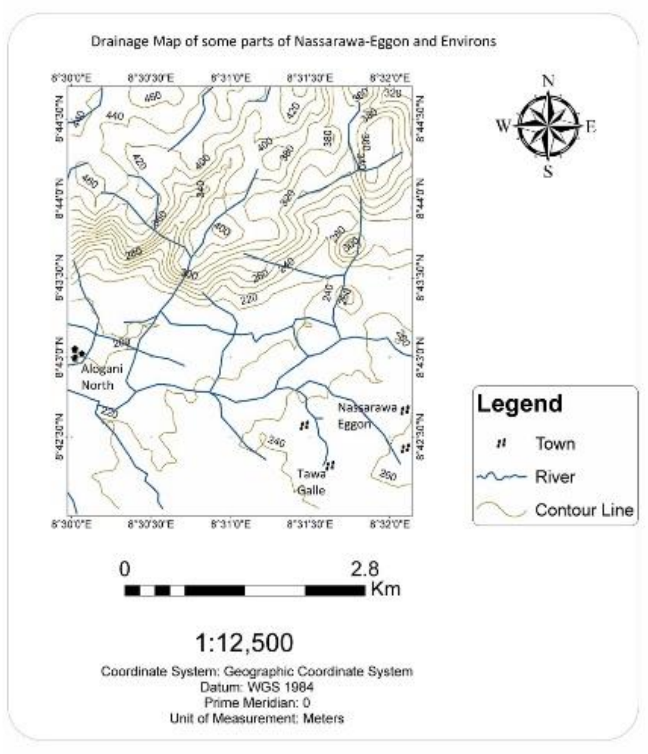

Figure 1. Topographic map of study area showing both relief and dendritic drainage pattern [9]

4. METHODOLOGY

Geological mapping was achieved by taking random traverses across the mapped area, to identify and record geological formations present and their associated structures. Scientific equipment/materials used include:

- A topographic map of the study area (scale of 1:12,500)
- A Global Positioning System (GPS) to obtain and record outcrop locations.
- A compass-clinometer used to measure the attitude of the geological structures seen, which were then recorded in the field notebook for further statistical analysis (plotting of rose diagrams) to obtain their general structural trend,
- Sledge and geological hammers used to obtain representative rock samples from the different rock units.
- Hand lens for megascopic description of rocks in the field.
- Measuring tape,
- Sample bags for carrying the rock samples,
- A digital camera for taking photographs of rocks and geologic features, and
- Stationeries (such as a field notebook, markers, sample site checklist, pencils and pens) for recording geologic details as observed on the field.

5. THE GEOLOGY OF THE STUDY AREA

The mapped area comprises of the Precambrian Basement complex rocks of Nigeria. Discrete rock units have been outlined on the geological map as shown in figure 2 below. Both the megascopic and miscroscopic descriptions of the rock types observed are also discussed below.

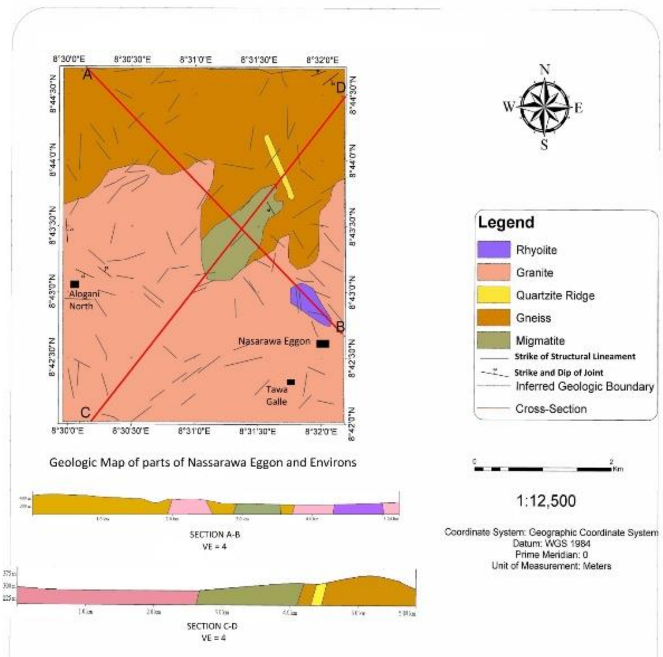

Figure 2. Geological map of the study area [9]

5.1 Megascopic description of rock types

Lithological units observed in the field were identified by determining their distinctive physical properties, which include their colour, mineralogy, texture, and the presence of structures such as foliation (strictly in the case of metamorphic rocks). This process is referred to as the megascopic description of rocks. A tentative name is given to the rock until petrographic analysis has been carried out to confirm the rock's identity. Rocks identified in the field include Migmatite, gneiss, granite, dolerite and granite.

5.1.1 Migmatite

An outcrop of migmatite was observed in the central area with a trend of 222°. It covers less than 10% of the study area. It has many stockworks and is highly fractured, with joints having a dominantly N-S trend. This rock has numerous sinistral strike-slip faults. The rock is highly foliated and predominantly melanocratic with leucocratic portions consisting of quartzo-feldspathic veins. The rock texture is medium grained, and exhibits ptygmatic structures.

Migmatite, a high grade metamorphic rock, is a mixture of both igneous material of granitic composition and high-grade metamorphic rocks characterized by a banded or veined appearance, and often accompanied by evidence of plastic deformation [4]. Theories for the origin of migmatites include the idea that the granitic material was introduced as magma or through the action of fluids permeating the host rock [4]. In most cases, migmatite appears to represent the most extreme case of metamorphism in which the less refractory components of gneiss start to melt, leading to the segregation of veins and patches of granitic liquid under conditions of elevated temperature, pressure and shear stress (Figure 3). Often Schlieren (pencil-like, discoidal or blade-like mineral aggregates, varying greatly in size) are developed in which streaked-out portions of the host rock (paleosome) enclose melted material (neosome) [4].

Figure 3. Photographs of migmatite taken at (8° 43’ 57.8” N and 8° 31’ 43.1” E) showing the segregation of veins, and strike-slip faults

5.1.2 Gneiss

Gneiss outcrops occur mostly in the north of the study area, occupying about 35% of the mapped area. These outcrops are more prominent at lower elevations as compared to the large granitic hills to the south. These rocks were observed to be highly fractured, contain quartz veins and empty joints with a dominantly NE-SW trend. It has some dextral strike-slip faults. The degree of foliation is low in a certain location making it appear as granite gneiss [15].

Gneiss, a foliated metamorphic rock, is formed under conditions of high grade regional metamorphism [22]. It is characterized by gneissic banding [19]; a layered appearance caused by the segregation of ferromagnesian minerals from quartzo-feldspathic minerals in discontinuous layers or lenticles (Figure 4). These ferromagnesians are commonly biotite and/or hornblende. Pyroxene is less common. Garnet, mainly almandine, could be present as an accessory mineral. The quartzo-feldspathic minerals, as the name implies, are composed of quartz and feldspar.

The colour index of the gneiss is leucocratic-mesocratic, while exhibiting a gneissose foliation (segregation of light and dark bands). The rock is fine- medium grained.

Figure 4. Photograph of gneiss taken at (8° 44’ 40.9” N and 8° 32’ 08.7” E)

5.1.3 Rhyolite

A rhyolite ridge was observed on the SE area close to a present day Fulani settlement. It appeared to be highly weathered into superficial clay deposits in certain locations.

Rhyolite is an extrusive rock commonly showing flow texture, and typically porphyritic, with phenocrysts of quartz and potassium feldspar in a glassy to microcrystalline groundmass (Figure 5). It is the extrusive equivalent of granite.

Its colour index is leucocratic to mesocratic. It is devoid of foliation. Although most of the rock’s mineral grains are unidentifiable megascopically due to its fine grained texture, they appeared to be composed of mostly quartz and feldspar (felsic minerals) with a few mafic minerals.

Figure 5. Photograph of small boulders of rhyolite taken at (8° 43’ 51.8” N and 8° 32’ 00.5” E)

5.1.4 Granite

Granite covers approximately 60 % of the mapped area, and it is observed to occur having the highest elevations. It appears as a large hill with an EW trend, cutting across the whole study area. These rocks are highly fractured; with most of its geologic structures having a dominantly NE-SW trend.

It is principally composed of quartz and feldspars. Biotite and /or hornblende are comparatively minute. Quartz may form between 20 and 60 per cent of the felsic components (although, feldspar is mostly higher in proportion to quartz), and alkali feldspar may also from 35 to 90 per cent of the total feldspar. The composition of the plagioclase is usually in the oligoclase/andesine range, while the alkali feldspar is the low temperature form, i.e., orthoclase, microcline, or the perthitic varieties. Common accessory minerals include apatite, zircon and magnetite, and sometimes tourmaline, titanite, fluorite and monazite [4]. Textures range from granular to porphyritic, with large euhedral phenocrysts (megacryts) of alkali feldspar. The granite observed was of medium grain size (Figure 6).

The colour index of the granite is leucocratic, and it is devoid of foliation. It is predominantly composed of feldspar and quartz; while hornblende and biotite are comparatively minute.

Figure 6. Photograph of medium grained granite at (8° 43’ 31.3” N and 8° 30’ 10.3” E)

5.1.5 Dolerite

Dolerite, observed occurring as a dyke and in close proximity to a migmatite outcrop, cuts across the granite. It covers a small lateral extent.

This is a medium grained intrusive igneous rock of basaltic composition. It is essentially composed of pyroxene, plagioclase (usually labradorite) and Fe-Ti oxides, and commonly exhibits the ophitic texture (a texture in which euhedral or subhedral plagioclase crystals are enclosed in pyroxene crystals, commonly augite) [4]. The name of the principal minor mineral may be added, e.g., olivine dolerite or quartz dolerite [4]. The rock as observed in the field can be called a quartz dolerite, since quartz crystals are observed to be the principal minor mineral seen (Figure 7).

The rock is melanocratic, and devoid of foliation. Mineralogically, it is composed of dominantly mafic minerals and some ferric material (iron oxide) with few acicular quartz grains. The rock is medium-grained.

Figure 7. Photograph of dolerite taken at (8° 44’ 29.4” N and 8° 32’ 22.0” E)

5.1.6 Quartzite

A Quartzite ridge was seen cutting across the gneiss in the NE area of the map. This ridge has a trend of 332°, covering a distance of approximately 1km and a width of 70m. It is highly fractured, with most of its fractures trending in the either the NNE-SSW or NNW-SSE direction.

Quartzite (metaquartzite) is a metamorphic rock consisting of primarily quartz grains, formed by the recrystallization of sandstone by thermal or regional metamorphism [4]. The outcrop was not well exposed due to the presence of vegetation cover.

The rock is white (Figure 8), and devoid of foliation. Mineralogically, the rock is composed of only quartz. It is fine-grained.

Figure 8. Photograph of quartzite taken at (8° 43’ 52.9” N and 8° 31’ 49.7” E)

6. RESULTS: THIN SECTION PETROGRAPHY

Petrography involves the systematic classification of rocks by means of microscopic examination. A petrographic or polarizing microscope is used to study rocks in thin sections, made by gluing a very thin rock slide on a transparent glass slide of a standard thickness of 0.03mm (in which most minerals are transparent and can be identified). It allows for the application of subtle diagnostic tests to be carried out on thin sections by observing their optical properties, such as colour, pleochroism, habit, and birefringence under both plane and crossed polarized light. Among the rocks identified in hand specimen from the field are migmatite, gneiss, rhyolite, dolerite, granite and quartzite.

Five representative samples were selected for petrographic examination from the various samples collected in the field. Those selected include: SAS 8, SAS 10, SAS 11, SAS 12, and SAS 14. Samples of Quartzite were not analysed since it is mono-minerallic (composed of quartz). Results of Petrographic Examination of rock samples under plane polarised light (PPL) and crossed polarised light (XPL) are discussed below.

6.1 Dolerite

Table 1. Modal composition of SAS 8 (Dolerite)

Mineral	Percentage composition (%)
Plagioclase Feldspar	70
Opaque Mineral	15
Olivine	10
Quartz	05

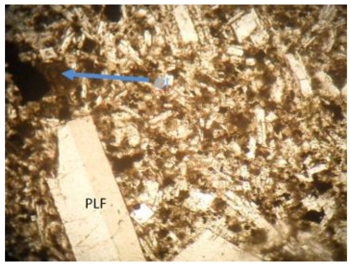

Figure 9. Photomicrograph of Dolerite (SAS 8) under PPL (Magnification ×10)

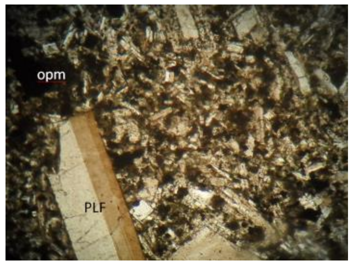

Figure 10. Photomicrograph of Dolerite (SAS 8) under XPL (Magnification ×10) (opm = opaque mineral, PLF = Plagioclase Feldspar)

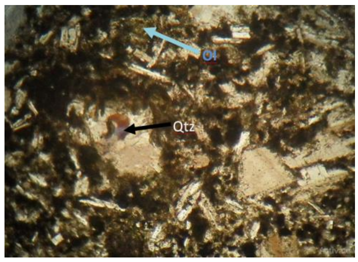

Figure 11. Photomicrograph of Dolerite (SAS 8) showing quartz under XPL (Magnification ×10) (Ol = Olivine, Qtz = Quartz)

6.1.1 Olivine

Under PPL

The mineral appears pale green to pale yellow with a low to moderate relief, and it is anhedral (Figure 9).

Under XPL

The mineral exhibits straight extinction with no twinning.

6.1.2 Plagioclase Feldspar

Under PPL

The mineral appears colourless with a moderate relief. It is subhedral to euhedral (contained as both phenocrysts and groundmass within the sample). It shows no signs of alteration.

Under XPL

The mineral exhibits simple albite twinning (Figure 10), and undergoes extinction at 57°. It does not appear zoned.

6.1.3 Opaque mineral

The mineral appears dark under both plane and crossed polarized light (Figure 10). It is possibly iron oxide.

6.1.4 Quartz

Under PPL

The mineral appears colourless with a moderate relief. It exhibits no pleochroism. It is subhedral to euhedral. It has an inclusion of the opaque mineral in one of the grains cut basally (Figure 11).

Under XPL

The mineral exhibits undulose extinction and no twinning.

6.2 Gneiss

Table 2. Modal composition of SAS 11 (Gneiss)

Mineral	Percentage Composition (%)
Quartz	40
Plagioclase Feldspar	30
Amphibole (Hornblende)	13
Mica (Biotite)	10
Opaque mineral	07

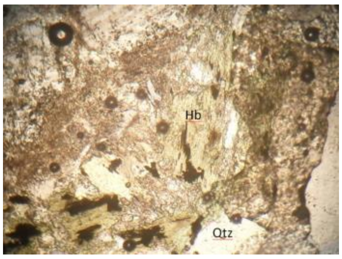

Figure 12. Photomicrograph of gneiss (SAS 11) under PPL (Magnification ×10) (Qtz = Quartz)

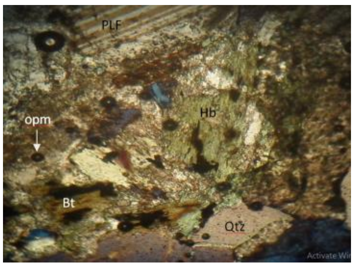

Figure 13. Photomicrograph of gneiss (SAS 11) under XPL (Magnification ×10) (PLF = Plagioclase Feldspar, Hb = Hornblende, Qtz = Quartz, Bt = Biotite, opm = Opaque mineral)

6.2.1 Amphibole (Hornblende)

Under PPL

The mineral appears green in colour with a high relief (Figure 12). It is anhedral and shows no cleavage.

Under XPL

The mineral exhibits straight extinction and no twinning.

6.2.2 Quartz

Under PPL

The mineral appears colourless (Figure 12) and has a low relief. It does not exhibit pleochroism. It has no cleavage and is anhedral.

Under XPL

The mineral exhibits undulose extinction and no twinning.

6.2.3 Plagioclase Feldspar (Albite)

Under PPL

The mineral appears colourless to cloudy and has a low relief. It is euhedral having one cleavage direction and shows signs of alteration.

Under XPL

The mineral exhibits albite polysynthetic twinning (Figure 13). It also exhibits straight extinction at 28°.

6.2.4 Mica (Biotite)

Under PPL

The mineral appears brown with a high relief. It exhibits pleochroism from light brown to dark brown (Figure 13). It is euhedral and shows a perfect cleavage.

Under XPL

The mineral exhibits straight extinction and is not twinned.

6.2.5 Opaque mineral

It appears dark in both plane and crossed polarized light (Figure 11).

6.3 Rhyolite

Table 3. Modal composition of SAS 12 (Rhyolite)

Mineral	Percentage Composition (%)
Quartz	45
Plagioclase Feldspar	30
Micro-perthite	15
Mica (Biotite)	10

Figure 14. Photomicrograph of Rhyolite (SAS 12) under PPL (Magnification ×10) (Qtz = Quartz)

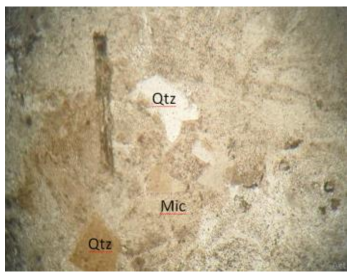

Figure 15. Photomicrograph of Rhyolite (SAS 12) under XPL (Magnification ×10) (Qtz = Quartz, Mic = Microperthite)

6.3.1 Quartz

Under PPL

The mineral appears colourless with a low relief (Figure 14). It is not pleochroic. The mineral is anhedral and has no cleavage.

Under XPL

The mineral exhibits undulose extinction and is not twinned.

6.3.2 Plagioclase Feldspar (Albite)

Under PPL

The mineral appears colourless to cloudy with a low relief. It does not exhibit pleochroism. It is anhedral to euhedral, showing cleavage in one direction.

Under XPL

The mineral does not exhibit extinction. It is slightly twinned.

6.3.3 Microperthite

It appears radial or like straw lines (Figure 15).

6.3.4 Mica (Biotite)

Under PPL

The mineral appears colourless with a high relief. It exhibits pleochroism, changing from colourless to pinkish green. It has an anhedral habit and show perfect cleavage.

Under XPL

The mineral exhibits oblique extinction and no twinning.

6.4 Migmatite

Table 4. Modal Composition of SAS 14 (Migmatite)

Mineral	Percentage Composition (%)
Amphibole (Hornblende)	60
Quartz	25
Plagioclase Feldspar (Albite)	15

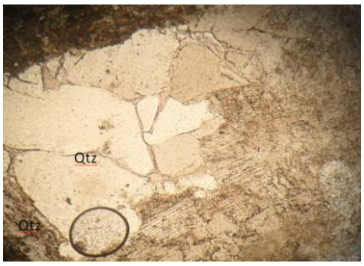

Figure 16. Photomicrograph of a granitic portion of migmatite (SAS 14) under PPL (Magnification ×10) (Qtz = Quartz)

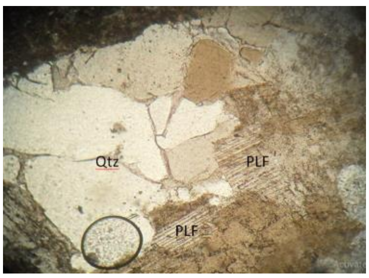

Figure 17. Photomicrograph of a granitic portion of migmatite (SAS 14) under XPL (Magnification ×10) (Qtz = Quartz, PLF = Plagioclase Feldspar)

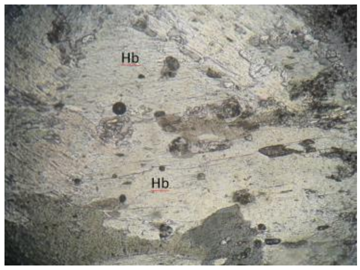

Figure 18. Photomicrograph of the metamorphic portion of migmatite (SAS 14) under PPL) (Magnification ×10) (Hb = Hornblende)

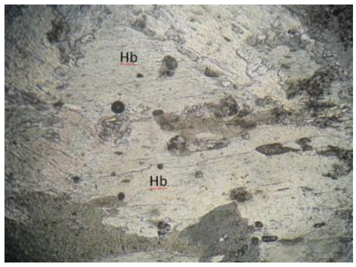

Figure 19. Photomicrograph of the metamorphic portion of migmatite (SAS 14) under XPL (Magnification ×10) (Hb = Hornblende, Qtz = Quartz)

6.4.1 Quartz

Under PPL

The mineral appears colourless with a low relief (Figures 16 & 17). It neither exhibits pleochroism nor cleavage. It is anhedral.

Under XPL

The mineral exhibits undulose extinction and is not twinned.

6.4.2 Plagioclase Feldspar

Under PPL

The mineral appears colourless and has a low relief. It does not exhibit pleochroism. It shows cleavage in one direction and is anhedral.

Under XPL

The mineral exhibits albite polysynthetic twinning (Figure 17) and undergoes extinction at 42°.

6.4.3 Amphibole (Hornblende)

Under PPL

The mineral appears light green with a moderate to high relief (Figure 18). It exhibits pleochroism, from blue to green to yellow. It is subhedral with a perfect cleavage. It has a sense of orientation.

Under XPL

The mineral exhibits straight extinction and no twinning (Figure 19).

7. STRUCTURAL GEOLOGY AND GEOLOGIC HISTORY

Geologic structures result when tectonic forces within the earth fold or break rocks, thereby creating deep faults [18]. Since rock deformation is facilitated by the chemical bond types holding rock minerals together, the mineralogical composition of a rock will have a major influence on the deformational behaviour of the rock. Minerals such as quartz, olivine, and feldspars are very brittle, while clay minerals and micas are more ductile. Brittle minerals are susceptible to fracturing, while ductile minerals are more susceptible to folding [15].

The presence or absence of water is also a determining factor in rock deformation. Thus, wet rock tends to behave in a ductile manner, while dry rocks tend to behave in a brittle manner [15].

As folding and faulting repeatedly occurs in rocks, the geology may become much more complex to understand and interpret. Most of these forces are related to tectonic activities.

Understanding the origin of these structures is critical in discovering more reserves for our non-renewable resources. Natural resources such as metallic ores and hydrocarbons, often form along, around and/or near geologic structures

Geologic structures observed within the research area include foliation, folds, fractures, veins, and dykes.

7.1 Foliation

The foliation known as **gneissosity** was observed on gneiss (Figure 20). This is the preferred orientation of mafic and felsic minerals (formed under differential stress) in the direction perpendicular to the direction of compressive stress [18-20]. This is common in rocks with a significant amount of sheet silicates, such as mica or acicular minerals (e.g., hornblende) [28]. These rocks are easily classified by their composition, grain size, and foliation type.

Figure 20. Photograph of the gneissosity found on gneiss taken at (8° 44' 40.9" N and 8° 32' 08.7" E)

7.2 Folds

Folds are bends or wave-like features that form during deformation of ductile rocks (most metamorphic rocks can be intensely folded because they are ductile under high temperature and pressure environments of deep burial and tectonic stresses). Ptygmatic folds were observed on the migmatite (Figure 21).

Figure 21. Photograph of ptygmatic folds found on migmatite at (8° 43' 45.1" N and 8° 31' 35.6" E)

7.3 Fractures

Fractures are formed as a result of cracking or rupturing of a rock body under stress. Brittle rocks fracture. There could be a shear displacement, slippage or offset in these cracks resulting in the formation of faults. Where there is no offset along the fracture, they are called **joints** (Figure 22). In the case of a shear displacement the fracture, this is referred to as a **fault** (Figure 23**).** Joints provide pathways for wall rock mineralization. Major joints were observed on the gneiss and granitic ridge, having a dominantly NE-SW trend, while faults observed were dextral strike-slip faults with different displacements.

Figure 22. Photograph of major joints found on different rocks (A) Not dipping at (8° 43' 49.0" N and 8° 32'07.2" E), (B) while dipping at (8° 43' 10.6" N and 8° 30' 07.6" E)

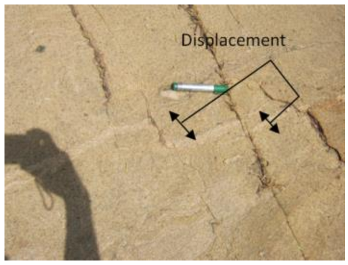

Figure 23. Photographs of dextral strike-slip faults found on rocks at (8° 43' 10.6" N and 8° 30' 07.6" E)

7.4 Veins

Veins are mostly associated with igneous and metamorphic rock bodies occurring as highly visible sheet-like bodies of crystallized minerals within a rock. Veins form when hydrothermal fluids are injected into open fractures, cool rapidly and then crystallize. Quartz veins observed in the field were found in different locations occurring mostly on gneiss (Figure 24). These quartz veins had varying dimensions (e.g., Vein 1: average length=10m; average width=3cm; Vein 2: average length=7m, average width=2cm; Vein 3: average length=80cm, average width=1cm, Vein 4: average length = 40cm, average width = 1.5cm).

Figure 24. Photographs of parallel quartz veins, found on gneiss and taken at (8° 44' 23.3" N and 8° 32' 14.0" E)

7.5 Dykes

Dykes are shallow intrusions that show a discordant relationship to the rocks in which they intrude (Figure 25). They may occur as isolated bodies or may occur as swarms of dykes emanating from a large intrusive body at depth. In this case, I observed many pegmatitic dykes varying in size (average length = 90cm, average width = 5.5cm; average length = 160cm, average width = 4cm), with a general N-S trend (Figure 23).

Figure 25. Photographs of a pegmatitic dyke found on gneiss taken at (8° 43’ 50.6” N and 8° 31’ 40.4” E)

8. DISCUSSION: THE GEOLOGICAL HISTORY OF THE STUDY AREA

8.1 The Nigerian basement complex rocks

The Nigerian basement complex rocks are well exposed in the central part of the study area, occurring as a chain of hills stretching from the east to the west. These basement rocks have been affected by at least four major orogenic cycles; the Liberian (2,700 Ma), the Eburnean (2,000 Ma), the Kibaran (1,100 Ma), and the Pan-African (600 Ma) orogenic cycles. The Liberian, Eburnean and Kibaran orogenies were characterized by intense deformation and isoclinal folding. The Pan African orogeny was characterized by regional metamorphism, migmatization, extensive granitization and gneissification, producing syn-tectonic granites and homogeneous gneisses [1]. The final stage of this last deformational cycle was characterized by the late tectonic emplacement of granites and granodiorites, and associated contact metamorphism. The orogeny was concluded by faulting and fracturing [7, 26]. On the basis of age relationship, the Precambrian Nigerian basement complex rocks observed in the field can be grouped into three, namely:

A. Migmatite-Gneiss complex.
B. The Older (Pan-African) Granites
C. Undeformed Basic Dykes.

8.1.1 Migmatite-gneiss complex

The Migmatite-Gneiss complex which is Neo-Proterozoic to Meso-Archean (542 Ma-3200 Ma) is represented by gneiss and migmatite within the study area. Gneiss was deformed and intruded by the older granites (Pan-African Granitoids) during the Pan-African episodes (600 ± 200 Ma). It is the most extensive rock type in the area. They are mostly medium-grained rocks, which are well-jointed with predominantly NNE-SSW trends. The pegmatite veins associated with these basement complex rocks have been recorded to have trends in the N-S, NNE-SSW, NE-SW and NNW-SSE directions [3].

8.1.2 The Older Granites (Pan-African Granitoids)

The term “older granite” introduced by Falconer [6], is used in distinguishing between the deep-seated, often concordant or semi-concordant granites of the Nigerian basement complex from the high-level, highly discordant tin-bearing Jurassic granites of Northern Nigeria [25]. These older granites range widely in age (750 - 450 Ma) and composition, representing a diverse and extensive magmatic cycle associated with the Pan-African orogeny [25]. They are generally observed to intrude the Migmatite-Gneiss Complex and the Schist Belts. The older granites suite is notable for its general lack of associated mineralization, although thermal effects may influence the remobilization of mineralizing fluids [25].

Rahaman (1988) classified the older granites solely on their textural characteristics rather than referring to the previous and broad classification of members of the older granites suite which was based on their texture, mineralogical composition and the relative timing of their emplacement [29].

The older granites within the study area are represented by pegmatitic veins; found to vary in size and having a dominantly NE-SW directional trend.

A granitic hill, which is deduced to be a Pan African granitoid was observed within the study area.

8.1.3 Undeformed basic dykes

The age of the basic dykes has an approximate age of 500 Ma [10], and are regarded as the youngest units in the Nigerian basement complex. The basic dykes are late to post-tectonic Pan African in age, and cut across the migmatite-gneiss complex, the schist belts and the older granites [25]. They are represented by dolerite, and less commonly by basaltic, felsic and lamprophyric dykes [5, 24].

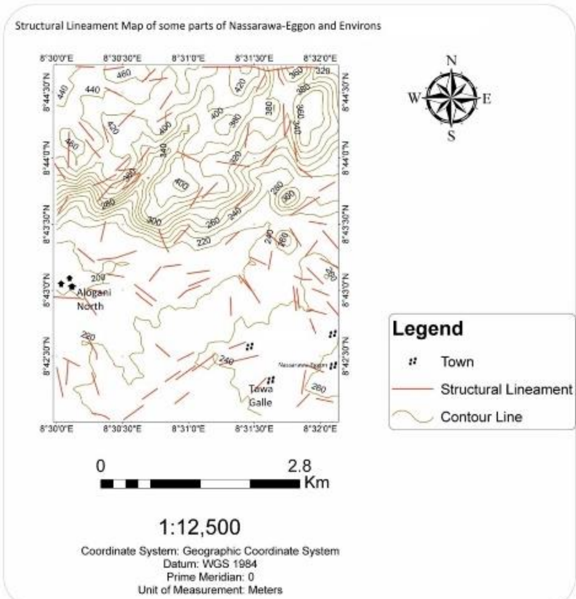

Figure 26. Structural Lineament Map of the study area [9]

A doleritic dyke was observed in the field with a NS directional trend intruding a rhyolitic ridge, which is congruent with the observations made by Obaje [25]. When they intrude basement complex rocks, they serve as determinants of the relative age of these basement rocks. Basic dykes could also suggest the existence of older basement windows within the Nigerian schist belts, aside their significant importance in isotope geochemistry sampling analysis and interpretation [5].

The quartzite and doleritic dykes seen cutting across/intruding the Gneiss most likely occurred as a result of Late to Post-tectonic Pan African activities [25].

From the general structural trend (NE-SW) obtained from rose diagram plots [8] of the geologic structures as observed on the rocks of the study area (Figures 26 & 27), it can be deduced that the direction of maximum stress of syn-tectonic and post-tectonic forces which affected these rocks; which is in the NW-SE direction (perpendicular to the strain/structures).

It is also noteworthy to conclude that the tectonic forces, acted upon these basement complex rocks after their emplacement (since the geologic structures are relatively younger than the Basement Complex rocks).

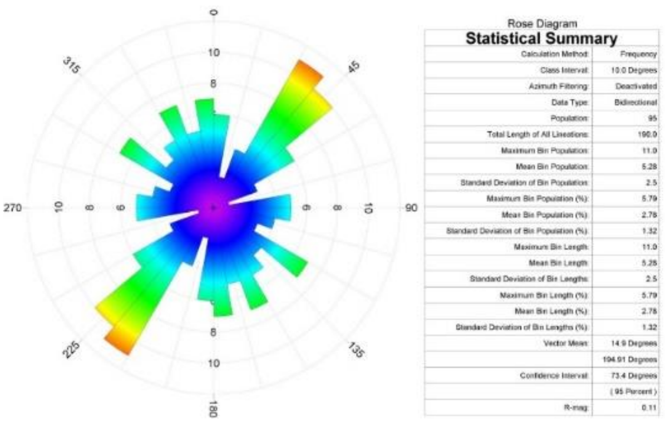

Figure 27. Rose diagram showing the general structural trend of lineaments in the mapped area (NE-SW) [9]

9. MINING ACTIVITIES WITHIN THE STUDY AREA

9.1 Mining geology

A mineral resource is a term used to describe the concentration of naturally occurring solid, liquid and gaseous materials in or on the Earth's crust in such a manner that economic extraction of the commodity is regarded as feasible, either currently or at some future time [13, 20, 21].

Potential economic mineral-bearing structures such as pegmatitic veins/dykes, quartz veins and joints were observed within the study area [16].

Economic mineral deposits can be classified on the basis of their means of concentration:

1. **Magmatic Ore Deposits** –economically valuable substances are concentrated within igneous rock through magmatic processes such as partial melting, crystal fractionation, and settling in a magma chamber. These mineral ores are concentrated in igneous rocks when elements that were once widely dispersed in low concentrations in the magma and concentrated and separated from the magma [20].

   An example of magmatic ore deposit observed on the field is pegmatite.

   Pegmatite is a silica rich residue formed during the late phase of fractional crystallization of magma. It is also rich in water and rare earth elements such as, Lithium, Niobium, Boron, Beryllium, Gold, and Uranium, which when highly concentrated are of great economic value [20]. This residue is often injected into rock fracture and crystallizes as a rock called a pegmatite that characteristically consists of large crystals. The pegmatite observed occurred as veins and dyke, though veins were most common.

   Pegmatite dykes were observed varying in size (Dyke 1: average length = 90cm, average width = 5.5cm; Dyke 2: average length = 160cm, average width = 4cm), with a general N-S trend.

   Also, quartz veins observed in the study area were found in different locations occurring mostly on gneiss. These quartz veins had varying dimensions (e.g., Vein 1: average length=10m; average width=3cm; Vein 2: average length=7m, average width=2cm; Vein 3: average length=80cm, average width=1cm, Vein 4: average length = 40cm, average width = 1.5cm). Rose plots of the pegmatitic veins and dykes seen found within the study area have a dominant structural trend in the NNE-SSW direction.

   These pegmatitic veins and dykes may be either mineralised or barren.

   Abandoned mining pits were seen on some hills at the central part of the mapped area, where artisanal miners had exploited for gemstones, such as amethyst, emerald and tourmaline.

2. **Sedimentary Ore Deposits** – These are secondary mineral deposits formed as a result of the concentration of ore minerals which have been weathered from mineralized rocks. Examples of these deposits include placer ore deposits and laterite [20].

- **Placer Ore Deposits** are concentrated by flowing surface waters such as river channels. The velocity of flowing water influences the means and distance of transportation of these minerals from the primary mineral deposit [20]. Heavy minerals like gold, diamond, and magnetite are deposited at a higher velocity than lower density minerals like quartz, despite being of the same size [20]. Thus, heavy minerals are concentrated in areas of low water current velocity [20]. The study area has the potential for placer deposits due to the presence of a few stream channels seen cutting across and possibly leaching mineralised rocks.
- **Laterite**

  Laterite (found in the south of the investigated area) is a source of secondary oxides of iron and aluminium [11]. These oxides are insoluble deposits of iron and aluminium, during chemical and physical weathering of mineralized rocks [11].

10. CONCLUSION

The study area is underlain mainly by the Nigerian Basement Complex rocks, which include migmatite, gneiss, quartzite, granite, rhyolite and dolerite (intruding the granitic rocks). These rocks are most likely Precambrian in age. The structures observed on these rocks in the field include, foliations (gneissosity), ptygmatic folds, pegmatitic dykes, quartz veins, joints, and sinistral and dextral strike-slip faults. The general structural trends of joints, foliation and quartz veins (NNE-SSW and NE-SW directions) are characteristic of the last known major orogenic activity within Africa, the Pan African orogeny (600Mya). This provides a tremendous insight into the direction of maximum stress of the syn- and post-tectonic forces which have acted upon these rocks, which is in the NW-SE direction.

The study area is enriched with economic mineral resources such as iron ore and amethyst, occurring as both magmatic and sedimentary ore deposits. These mineral deposits are concentrated in sufficient quantities for economic exploitation.

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NOMENCLATURE

Bio	Biotite
E	East
Hb	Hornblende
Mic	Microcline
N	North
Ol	Olivine
PFL	Plagioclase Feldspar
PPL	Plane Polarized Light
Qtz	Quartz
S	South
W	West
XPL	Cross Polarized Light