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RESEARCH ARTICLE

PETROGRAPHIC STUDIES AND PHYSICO-MECHANICAL PROPERTIES OF BIRIMIAN GRANITOIDS – A CASE STUDY OF OYOKO GRANITOIDS COMPLEX IN KOFORIDUA

Matthew Coffie Wilson*, Rosalia Appiah Mangue Amankwah, Samuel Kow Ansah, Selase Nani, Dennis Asante

Kwame Nkrumah University of Science and Technology, Department of Geological Engineering, University Post Office, Kumasi – Ghana
****Corresponding Author E-mail: regimatt2003@yahoo.co.uk; mcwilson.coe@knust.edu.gh***

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ABSTRACT

The study investigated the physico-mechanical and petrographic properties of the basin-type granitoids of the Oyoko granitoid complex, to establish their strengths for engineering properties. The results obtained from this work will therefore be necessary in knowing the competences of the rocks for various engineering construction works. The purpose of this research is to determine the physico-mechanical and microstructural features of the granitoid suites of rocks at Oyoko. Thin sections were prepared and microscope used for the petrological studies of the rocks, whilst UCS test was conducted for the strength of the rocks. The Oyoko granitoid complex rocks were petrologically identified to be biotite gneisses, pegmatite and migmatite. The rocks at the study area have received little attention in mechanical and petrographic studies. These granitoid rocks have preserved porphyritic textures and consist of mineral assemblage such as biotite, quartz, plagioclase feldspar, alkali feldspar, amphibole, clino-pyroxene, chlorite, etc. The recrystallization of the plagioclase feldspar imply that these rocks have experienced some level of deformations. The foliated granitic gneisses intruded the older rock units, some of which had been subjected to earlier tectonism. The migmatite defines the area to be closer to a contact zone. The major structural features in the migmatite rocks were ptygmatic folds. The UCS value for the biotite gneiss of 91.6 N/mm^2 gives a more representation of the general rock strength of the study area. The biotite gneisses at the study area may be classified to be mechanically strong and recommended for road construction and engineering works.

KEYWORDS

Oyoko Granitoid, Mechanical Properties, Petrography, Migmatites, Biotite Gneiss

1. INTRODUCTION

Koforidua lies within the Densu River Basin, which is close to the southeastern base of the Kwahu Plateau. The Densu River basin, the major basin of the study area, encompasses three geological formations. These are the Cape Coast granite complex, Birimian supergroup and the Togo series. These geological formations cover a large part of the basin (90 %) (Adomako et al., 2015). The Birimian Supergroup is divided into the Lower Birimian and the Upper Birimian (Smith et al., 2016). The Lower Birimian consists of dacitic volcaniclastics, rhyodacitic volcaniclastics, greywackes, phyllites, argillites and chemical sediments (Leube and Hirdes, 1986). The Upper Birimian also consist of tholeiitic basalts with intercalated volcaniclastics, pyroclastic lava and hypabyssal basic intrusions. Most of the rocks have metamorphosed into calcareous chlorite schists and amphibolites (greenstones) (Adomako et al., 2015). Rock types found within the Birimian formation are sandstones, tuffs, grit, quartzites and some breccias. The Togo Series occurs in the southeastern part of the area and forms the estuary of the Densu River basin (Adomako et al., 2015). It makes up roughly 6 % of the catchment, and the rocks are highly folded and jointed. The Togo Series consists of sandstone, quartzite and quartz schist, shale, phyllite and some talc mica schist (Adomako et al., 2015).

This project was carried out at Oyoko (Figure 1) in the Eastern region of Ghana, situated in the New-Juaben Municipal District. It lies 4km northwards of Koforidua, the regional capital. The Oyoko granitoid complex forms part of the Birimian supergroup and the dominant rocks are gneisses and migmatites (Adomako et al., 2015). The major geological formation of the study area is the Birimian metasedimentary rocks of the Paleoproterozoic age with the associated basin granitoids complex. Amphibolites, biotite gneisses, migmatites and pegmatites make up the area of study.

Petrographic analyses are significant in determining the mineral assemblages that form a particular rock type. Petrographic studies provide understanding into the evolution of rock suites in an area and also the major deformations occurring in the rocks. Strength tests are also relevant in the determination of the mechanical properties which can be used to classify the rocks in terms of their competences based on the mechanical properties. The rocks of the study area have received little attention in mechanical and petrographic studies. Due to the lack of baseline information petrography, further works have not been carried out to determine the rock types, their genesis, mechanical properties and also their use for any engineering construction works.

The purpose of this project is to determine the physico-mechanical and microstructural features of the granitoid suites of rocks at Oyoko. To arrive at the aim, the mineralogy and the possible micro-structures within the rocks as well as the strength properties of the rocks and the rate of their competences had to be determined. This project provides intensive understanding data on the petrographic and physico-mechanical properties of the granitoid complexes in the study area. The results obtained from this work will therefore be necessary in knowing the

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competences of the rocks for various engineering construction works.

Unconfined Compressive Strength (UCS) test is one of the most commonly used rock engineering tests for strength determination. The mean UCS and its variable are often assumed to represent a reliable rock material property (Bieniawski, 1967). The UCS test records the collapse load during uniaxial loading of a cylindrical specimen. The UCS is an index parameter, hence, a proxy for rock strength which depend on the loading rate, specimen geometry, specimen size, and many other factors (Bieniawski, 1967; Hudson et al., 1971; Bieniawski, 1967).

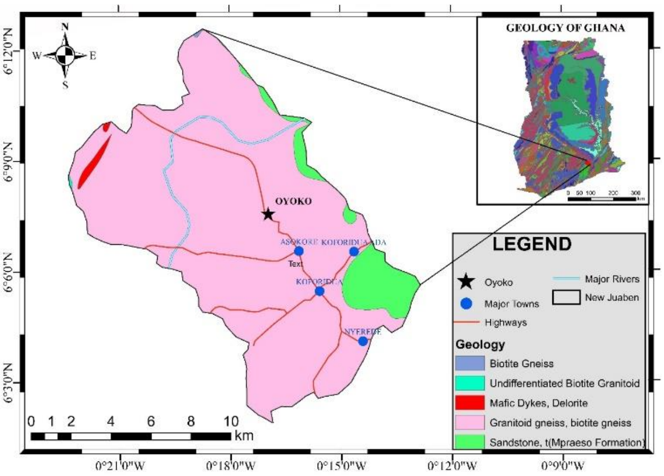


Figure 1: Map of Ghana locating Oyoko showing the geology, neighboring towns and morphology in the Eastern region (Ghana Geological Survey Department, 2009).

2. GEOLOGIC SETTING

The West African Craton (WAC) covers a larger part of Ghana which stabilized during the early Proterozoic age (2.5 billion years ago) in the Eburnean Orogeny. The southeastern part of Ghana is geologically complex. It includes three structural domains. The southeastern margin of the West African Craton, consisting of Archean to Paleoproterozoic assemblages, that have undergone the Eburnean Orogeny, the Neoproterozoic Volta Basin represented by its lower and middle mega sequences (Bombouaka and Oti Supergroups) and the frontal structural units of the Pan-African Dahomeyide Orogenic Belt (Tairou et al., 2012). The Stable Zone corresponds to the southeastern margin of the Leo-Man Shield and its Neoproterozoic cover, represented by the Volta Basin. In southeast Ghana, the Stable Zone is mainly composed of Archean to Paleoproterozoic rocks involved in the Eburnean thermo-tectonic events and stabilized at the end of this orogeny. The Eburnean orogeny was not strongly rejuvenated during the Pan-African thermo-tectonic events (Tairou et al., 2012).

The study area is a small community within the New Juaben North Municipality of Eastern region, called Oyoko (Figure 1). It is located between Asokore and Suhyen. It is 4 kilometers north of Koforidua with coordinates: 6^0 06' N and 0^0 16' W, 6^0 07' 29.95''N and 0^0 07' 57.431''W, 6^0 07' 30.056''N and 0^0 16' 56.808''W, 6^0 07' 33.160''N and 0^0 16' 58.117''W.

The Oyoko granitoids fall within the basin type granitoids previously called the Cape Coast granitoids. This group of granitoids consists of gneisses which are enveloped in the metasedimentary basins of the Birimian. They are syn-orogenic and may have been formed from granitization and partial melting of the Birimian metasediments and remobilisation of older basement rocks of WAC (Nyame, 2013). They are characterized by foliations subparallel to that of Birimian.

They are typically biotite and amphibolite bearing. These have been intruded by potassium-rich microgranite, dolerite and hornblendite. The intrusives occupy fractures or weak zones created as a result of tectonic activities (Woode, 1994). The gneisses occur alongside the migmatites, which were emplaced at deep crustal levels (Opare–Addo and John, 1993). At least, the two types of metamorphism that exist in the granitoids are progressive and retrograde metamorphism. The amphibolite facies assemblage of the progressive metamorphism was overprinted by the greenschist facies assemblage of the retrograde metamorphism (Woode, 1994).

3. MATERIALS AND METHODOLOGY

Some of the complex granitoid specimen were sampled and the rocks taken to the Kwame Nkrumah University of Science and Technology (KNUST) Geological Engineering Lab for thin section preparation and microscopic examinations and some of the rocks to the Civil Engineering Lab for UCS examination.

3.1 Laboratory Works and Analyses

3.1.1 Description of Hand Specimen

The various samples were observed with the aid of the hand lens. The purpose of this is to identify the physical properties and to determine the type of the samples. The properties include the colour, the grain distribution and the sizes of the individual grains or minerals of the rocks. The hand lens provides a magnification which makes it easy for identification of the various minerals in the sample.

3.1.2 Thin Section Preparation

Thin sections were prepared to enable the minerals well identified microscopically. The experiments (both petrographic and mechanical) were prepared at the Geological Engineering laboratory (KNUST) between April and June, 2021. A petrographic thin section is a 30 micro meter thick slice of rock mounted on a glass microscope slide and covered with cover glass. The thin sections are viewed under the microscope to identify the minerals, as well as the structures present in the samples.

Procedure:

A slab was cut from the sample with the rock cutting machine; the chip was hand ground with 60, 120, 240, 400, 600, 1200 grit; one side of the chip was labelled and the other side was impregnated with epoxy; the excess epoxy was trimmed and the section was labelled; the chip was then left to dry for 48 hours; the chip was trimmed using the chip trim saw machine; the section was polished on the Hill Quist thin section machine to obtain a 30 micrometre chip; the section was washed and labelled; the section was then viewed under the microscope for mineral analysis.

A total of four samples were cut. Each sample was cut in the three dimensional planes, X, Y and Z in order to have a better view of the mineral grains in all these directions. During this activity, physical and optical properties were extensively studied with the aid of the Leica polarizing microscope with 5x magnification. The major properties of interest included the shape of the mineral (habit), colour, relief, pleochroism, birefringence and extinction angle. To identify the rock types, the mineral associations and textural features were also included in the study.

3.1.3 Laboratory Testing of Rock Samples using Unconfined Compressive Strength Testing: Procedure

Samples for the Unconfined Compressive Strength (UCS) test were obtained by drill cores and were selected cautiously in order to be representative of the original rock formation. The diameter to length ratio of the drilled cores used for the UCS test was 1:2 according to American Society for Testing and Materials (ASTM). The cylindrical surfaces were prepared to be flat and smooth (thus the ends of the samples were levelled).

- Test specimens were cored using a core machine into circular cylinders, having height to diameter ratio of 2.0 and diameter of preferably not less than NX core size, approximately 52mm.

- The diameter of the specimen was related to the largest grain in the rock by the ratio of at least 10:1.

- The ends of the specimen were flattened to 0.02mm and did not depart from perpendicular axis of the specimen by more than 0.001 radian (about 3.5min) or 0.05mm in 50mm.

- The sides of the specimen were made smooth and free of abrupt irregularities and straight to within 0.3 mm over the full length of the specimen.

- The diameter of the test specimen was measured to the nearest 0.1 mm by averaging two diameters measured at right angles to each other at about the upper-height, the mid-height and the lower height of the specimen. The average diameter was used for calculating the cross-sectional area. The height of the specimen was determined to the nearest 1.0 mm.

- Samples were stored, for no longer than 30 days, in such a way as to preserve the natural water content, as far as possible, and tested in that condition. Based on Method 1, ISRM Committee on Laboratory Tests, Document No. 2, First Revision, December 1977.

- Load on the specimen was applied continuously at a constant stress rate such that failure occurred within 5-10min of loading.
- The maximum load on the specimen was recorded in mega Pascal (MPa).

3.1.3.1 Rock Coring and Trimming

Samples are obtained by drill cores and selected carefully in order to be representative of the original rock formation. The minimum diameter of a specimen must be at least 47 millimeters and ten times larger than the size of the largest mineral grain or 6 times larger for weaker rocks. The samples' length to diameter ratio (L/D) must be between 2.0 and 2.5 according to ASTM (American Society for Testing and Materials). The cylindrical surfaces are prepared to be flat and smooth. The samples' ends must be leveled within a 0.02 millimeter tolerance and they should not depart from perpendicularity by more than 0.06 degrees. The significance of this procedure is to preserve the in-situ properties of the sample until the test is conducted. Therefore, the moisture recorded in the field should also be preserved until testing. At least five samples are required to achieve a reliable value of the UCS.

4. RESULTS AND DISCUSSIONS

4.1 Petrographic Description

4.1.1 Macroscopic Description

Sample A

The rock sample (Figure 2A) is composed of very coarse equal granular pink minerals which may be alkali feldspar minerals. It also contains well defined granular quartz grains. The rock sample contains biotite grains which are fused into the surrounding quartz and feldspar grains. The rock is dominated by the pink coloured minerals. A section of the rock is entirely composed of biotite. There are medium-grained light green minerals fused with the quartz and pink minerals. There are tiny shiny minerals (pyrite) in the rock. There is alternating felsic and mafic bands of minerals. However, the felsic minerals dominate that of the mafic. This rock may be granitic gneiss.

Sample B

The minerals in the rock sample (Figure 2B) are aligned and separated into white and dark components, giving it a banded texture. There are megacryst minerals included in the dark minerals. Towards the base of the sample, there are fine texture minerals possessing brown colouration. The sample is dominated by dark coloured fine to medium equal granular materials. The rock sample contain pinkish and thus alkali feldspars. The felsic and mafic bands of minerals alternating renders the rock to be a gneiss.

Sample C

The rock sample (Figure 2C) is composed of coarse grained smoky-grey and pinkish feldspar minerals with most dominant whitish quartz grains. There are also large grains K-feldspars. The very coarse-grained minerals depict the minerals have been crystalized at depth and thus renders the rock to be pegmatitic.

Sample D

The rock sample (Figure 2D) has feldspathic phenocrysts. The veins intruded the medium grained rock at the time of metamorphism. The sample rock is characterized by ptygmatic folds. The sample rock has the felsic grains dominating in the matrix relative to the mafic minerals. Generally, on a macroscopic scale, the Biotite gneiss is characterized by dark biotite minerals and amphibole arranged in banded streaks giving the rock a gneissic texture. They possess medium to coarse grain, light grey colour mostly composed of feldspars, quartz and dark mafic minerals (amounts of biotite).

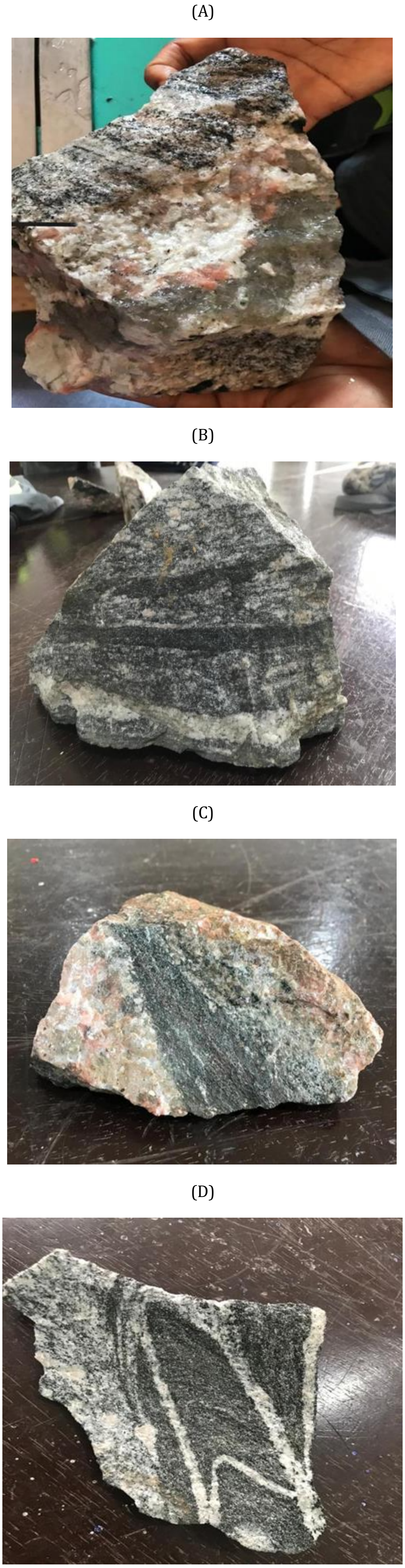


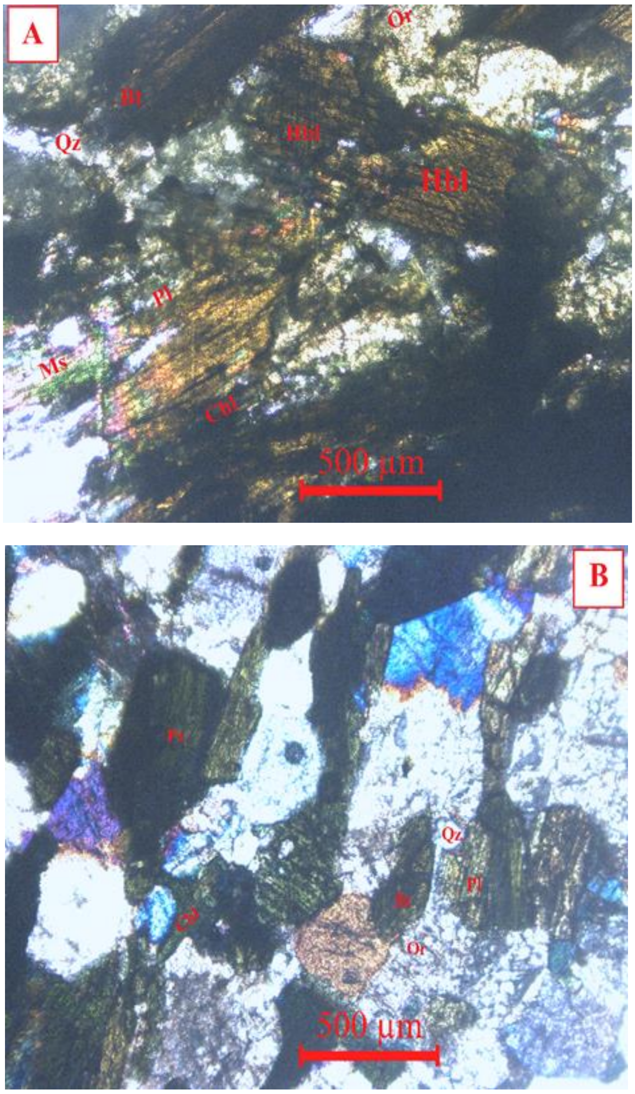
Figure 2: Macroscopic images of rocks sampled at the Oyoko granitoid

complex rocks showing: porphyritic texture (A); banding of mafic and felsic minerals (B); very coarse and dominant quartz grains and large feldspar grains (C); ptygmatic folds portraying migmatitic gneiss (D).

4.2 Microscopic Description

The framework of Figure 3 shows interlocking grains of medium to coarse sizes However, there is incipient recrystallization at the contact boundaries of many of the grains/crystals. The quartz crystals are mostly monocrystalline; however, few polycrystalline grains were observed comprising of at least two grains, with different extinction. The undulose extinction of the quartz depict deformation. The orthoclase crystals are differentiated from the quartz crystals by their cloudy appearance in PPL. The plagioclase feldspars look cloudier than the orthoclase feldspar crystals. Occasionally, some of the plagioclase show slight zonation probably due to alteration. However, alteration of some of the primary minerals (plagioclase and orthoclase) have also produced fine grained sericitic materials in the framework. Some of the biotite are altered into chlorite (Figure 3) to signify low grade metamorphism in the rock sample. This is probably due to the shearing during the deformation. Though the quartz is mostly monocrystalline, the polycrystalline grains suggest that the rock has suffered straining to a certain degree. The few dispersed hexagonal strong greenish minerals with intersection of the cleavage planes in the framework are hornblende (amphibole).

Structurally, the alignment of the platy minerals (biotites and chlorites) give the sample the foliated nature (Figure 3 A and B). Few dark and altered greenish subhedral crystals with blurred edges appear to be rotated to suggest shearing. The main structural domain of the rock specimen is the altered biotite to chlorite which is seen to be the foliation whilst the microlithons are the other phenocrysts in the framework; this is also another evidence of deformation in the framework (Figure 3 A and B).



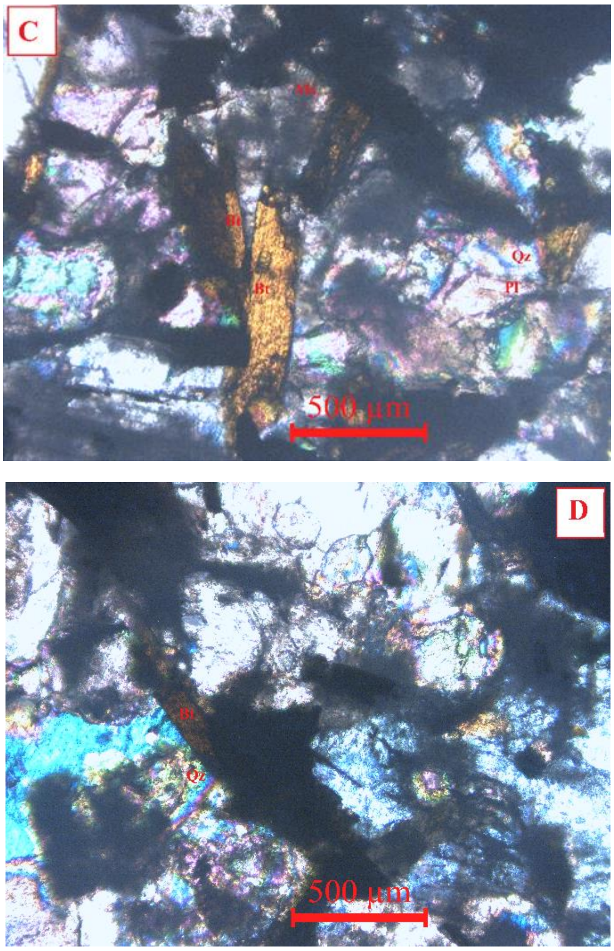
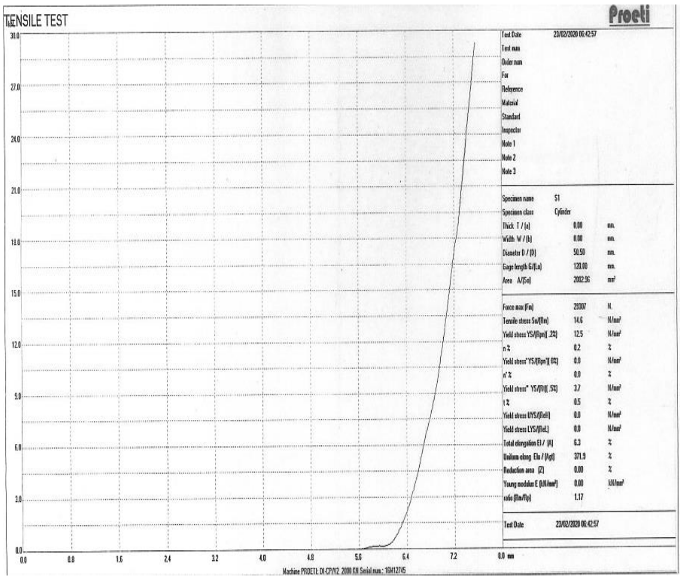


Figure 3: Photomicrographs of Oyoko granitoid complex (5x magnification) in Ghana showing various minerals and depicting their rock types such as: (A) biotite gneiss; (B) gneiss; (C) pegmatite; and (D) migmatite

The framework of the rock sample in Figure 3C is composed of medium to coarse irregularly-crystallized (non-directional textures) minerals without significant quantity of groundmass. The specimen is composed of interlocking grains of minerals giving the entire rock its coarse grained igneous character. It may be observed that the biotite flakes, amphibole and clino-pyroxene in the rock are dispersed in the framework. The platy minerals of muscovite and biotite are oriented to give the rock the foliated fabric. Some of the pegmatite fragments (example quartz and plagioclase feldspar) show evidence of recrystallization with growth of secondary muscovite although, in general, they are unmetamorphosed. The undulose extinction of the quartz and the sericitized and sheared biotite all depict deformation and tectonically shattered zone. The phenocrysts in the matrix are composed of mainly quartz, biotite, muscovite, orthoclase, pyroxene and plagioclase feldspar materials. The rock is slightly deformed. Some of the plagioclase feldspar reveal deformation lamellae, whilst some show recrystallization. Portions or the entire edges of some of the feldspars (orthoclase and plagioclase) as well as the muscovites show signs of varying degree of alterations. In certain cases, the entire minerals (example biotite) have been altered. The alterations have produced sericites which form part of the matrix in the framework. Structurally, the sample may have been deformed probably by some degree of shearing causing partial alignment. The crystalline igneous rock is foliated with the foliation resulting from preferred orientation of mainly elongated platy biotite and muscovite. The few subhedral hornblende crystals seen in the crystalline rock have blurred edges and appear to be rotated to suggest shearing. It may be inferred that the sample is a plutonic rock and may be coming from either weakly sheared zone or near a sheared zone that is mildly metamorphosed.

The specimen framework of Figure 3D consists of subhedral to anhedral crystals of varying sizes with extremely little fine size crystals. The medium size crystals dominate in the framework. Some of the coarse quartz crystals have irregular fracture planes within them. Though the quartz is mostly monocrystalline, some polycrystalline grains were observed suggesting that the rock has suffered straining to a certain degree. The oriented biotite flakes (Figure 3D) and elongated opaque minerals constitute the thin slightly dark bands that were observed in hand specimen. The orthoclase and microcline crystals show cleavage planes in a direction parallel to their lengths. Some of the quartz show fracturing. There is recrystallization as shown by the merging of some quartz crystals. The quartz, orthoclase and microcline constitute the light coloured band as seen in the hand specimen. Structurally foliation in the core is shown by the migmatite characteristics (Figure 3D) where the light minerals have been separated from the dark minerals. Thus, metamorphism in the rock is advanced probably approaching high grade.

4.3 Strength Analysis



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Reference		
Material		
Standard		
Inspector		
Note 1		
Note 2		
Note 3		
Specimen name	S1	
Specimen class	Cylinder	
Thick T / (a)	0.00	mm.
Width W / (b)	0.00	mm.
Diameter D / (D)	50.50	mm.
Gage length G/(Lo)	120.00	mm.
Area A/(So)	2002.96	mm²
Force max (Fm)	29307	N.
Tensile stress Su/(Rm)	14.6	N/mm²
Yield stress YS/(Rpn)(.2%)	12.5	N/mm²
n %	0.2	%
Yield stress' YS/(Rpn')(.0%)	0.0	N/mm²
n' %	0.0	%
Yield stress" YS/(Rt)(.5%)	3.7	N/mm²
t %	0.5	%
Yield stress UYS/(ReH)	0.0	N/mm²
Yield stress LYS/(ReL)	0.0	N/mm²
Total elongation El / (A)	6.3	%
Uniform elong. Elu / (Agt)	371.9	%
Reduction area (Z)	0.00	%
Young modulus E (kN/mm²)	0.00	kN/mm²
ratio (Rm/Rp)	1.17	
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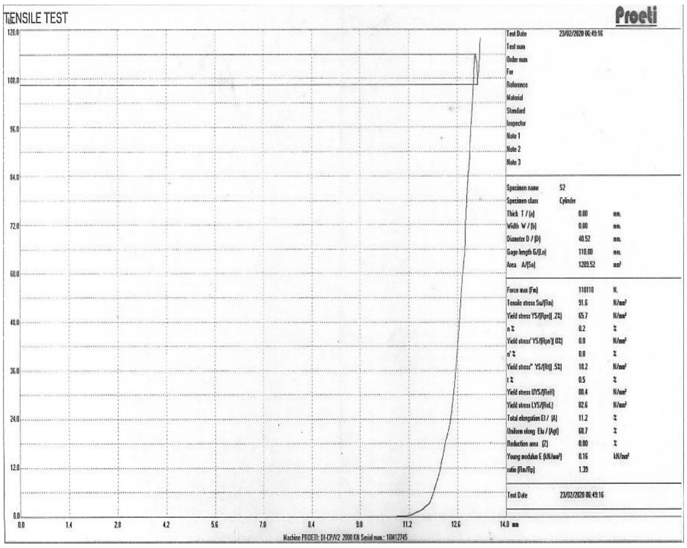
0.0 mm

Figure 4A: Uncompressive strength test graph for biotite gneiss 1 with tensile stress of 14.6N/mm^2



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Test num		
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Material		
Standard		
Inspector		
Note 1		
Note 2		
Note 3		
Specimen name	S2	
Specimen class	Cylinder	
Thick T / (a)	0.00	mm.
Width W / (b)	0.00	mm.
Diameter D / (D)	40.52	mm.
Gage length G/(Lo)	118.00	mm.
Area A/(So)	1289.52	mm²
Force max (Fm)	118110	N.
Tensile stress Su/(Rm)	91.6	N/mm²
Yield stress YS/(Rpn)(.2%)	65.7	N/mm²
n %	0.2	%
Yield stress' YS/(Rpn')(.0%)	0.0	N/mm²
n' %	0.0	%
Yield stress" YS/(Rt)(.5%)	18.2	N/mm²
t %	0.5	%
Yield stress UYS/(ReH)	88.4	N/mm²
Yield stress LYS/(ReL)	82.6	N/mm²
Total elongation El / (A)	11.2	%
Uniform elong. Elu / (Agt)	68.7	%
Reduction area (Z)	0.00	%
Young modulus E (kN/mm²)	0.16	kN/mm²
ratio (Rm/Rp)	1.39	
Test Date	23/02/2020 06:49:16	

14.0 mm

Figure 4B: Uncompressive strength test graph for biotite gneiss 2 with tensile stress of 91.6N/mm^2

The UCS of the samples are summarized in Table 1. The mean UCS of the samples is 53.1 N/mm^2 which classifies the rock to be moderate. The samples were classified using classification after Attewell and Farmer (1976).

Table 1: Uniaxial Compressive Strength Test of the biotite gneiss samples

SAMPLE ID	UCS (N/mm^2)	CLASSIFICATION
S1	14.6	very weak
S2	91.6	Strong

The UCS value of 14.6 N/mm^2 for rock sample S1 is not representative of the rock type due to the presence of fracture in the sample. The UCS value for the rock sample S2 (gneiss) of 91.6 N/mm^2 gives a more representation of the general rock strength of the study area.

Table 2: Classification of rock hardness (Attewell and Farmer, 1976)

Strength classification	Strength range (MPa)	Typical rock types
Very weak	10-20	Weathered and weakly-compacted sedimentary rocks
Weak	20-40	Weakly-cemented sedimentary rocks, schists
Medium	40-80	Competent sedimentary rocks; some low-density coarse-grained igneous rocks
Strong	80-160	Competent igneous rocks; some metamorphic rocks and fine-grained sandstones

The biotite gneiss is dominated by light pink to grey coarse grained phenocrysts of k-feldspars, plagioclase mineral gives a distinctive simple twinning. The rock sample also contains quartz and biotite minerals. The rock has preserved porphyritic textures.

5. CONCLUSION

The rocks identified from the study area were categorized broadly into biotite gneisses, pegmatite and migmatite. The rocks were formed during mantle fractionating where mafic minerals initially crystallize out of magma while silica content simultaneously increases. Microscopically, the biotite gneiss is medium- to coarse-grained rock. The mineral assemblage includes biotite, quartz, plagioclase feldspars, amphibole, orthoclase and clinopyroxene. The elongated dark mineral aligns to form banded nature of the gneiss. Quartz shows distinctive grain boundary. The rock shows foliation by the segregation of black and white mineral grains into distinctive bands. From the petrographs, the plagioclase feldspars recrystallized in between the orthoclase and the microcline. The recrystallization of the plagioclase implies that these rocks have experienced some level of deformations. There are also alterations in the biotite which is evident in it showing variation of colors from dark brown to green. This may be due to the presence of water within a suture zone. The quartz grains show undulose extinctions which is an evidence of straining (deformation).

The different rock types at the Oyoko granitoid complex depict different forms of deformation. The migmatite rocks show anatexis character since some of the minerals undergo recrystallization, melting, re-melting and partial melting; thus there is an indication of flow of minerals. The migmatite rock defines the area to be closer to a contact zone.

Biotite gneisses are characterized by dark biotite minerals arranged in banded streaks giving the rock a gneissic texture. They possess medium to coarse grains, light grey colour and mostly composed of feldspars, quartz and dark mafic minerals (amounts of biotite). The mineral assemblage includes: biotite, quartz, plagioclase, clinopyroxene, amphibole and microcline. The pegmatite also contain quartz, plagioclase, biotite minerals, as well as light pink to grey coarse grained phenocrysts of K-feldspars. The migmatite also consists of quartz, feldspars and few biotite minerals.

The rock samples (the biotite gneisses) of the study area, according to the classification by Attewell and Farmer, 1976, classify as strong (91.6 N/mm^2). The biotite gneiss may be classified to be mechanically strong and belongs to competent igneous and metamorphic rocks. These rocks may be recommended to be useful for road construction.

The preferred source of the granitoids was subducted hot oceanic crust with high degree of partial melting. The foliated granitic gneisses intruded the older rock units, some of which had been subjected to earlier tectonism. The major structural features in the migmatite rocks were ptygmatic folds and some fractures.

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