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RESEARCH ARTICLE

PETROLOGICAL AND MECHANICAL PROPERTIES OF THE DAHOMEYAN GRANITIC ROCKS – A CASE STUDY AT GREEN VALLEY AND AKROFU

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ABSTRACT

The main aim of this project is to determine the structures, petrography, strength and competence of Dahomeyan granitic rocks at Green Valley and Akrofu in Ghana and compare them from both localities in terms of their mineralogical composition and strength properties. Thin sections were prepared with rock samples from the field at the KNUST Geological Engineering Laboratory and petrographic microscope used to determine the different types of minerals in the samples and also the rock type. The mechanical strengths of the rocks were determined at the KNUST Civil Engineering Laboratory using Schmidt Hammer device. The studied Dahomeyan rocks at both Akrofu and Green Valley are respectively classified as granodiorite and biotite granitic gneiss. The mineralogical composition of different modal percentages includes quartz, feldspars, biotite, muscovite and hornblende. The presence of fractures and foliations due to a mafic biotite mineral indicate deformations rocks. The granodiorite is classified as weak rock with compressive strength of 23.50 MPa. This is due to higher fractures in the rock. In conclusion, the higher the presence of high grade of fractures and foliations due to biotite mineral, the weaker the strength of the rock. The biotite granite gneiss at Green Valley can thus be useful as crushed stone in road construction as well as for building material. For the rock texture, coarser mineral fabric corresponds to higher uniaxial compressive strength. The strength of these granitoids were influenced by the climatological changes as well as the intensity of weathering they had undergone within the area.

KEYWORDS

Dahomeyan granitic rocks, petrography, strength properties, granitic rocks, rock structures

1. INTRODUCTION

The Dahomeyan rock group is Ghana's easternmost rock group, and it differs significantly from other Ghanaian rocks in that it is composed of high-grade metamorphic rocks. It is located in the southeastern corner of Ghana, roughly along a line drawn north-northeast from Accra to intersect the Ghana-Togo border near Agome in Togo. The system, which lies beneath the Accra planes, covers an area of approximately 7000 square kilometers. The Dahomeyan System is made up of Birimian or younger formations that were involved in the Pan African thermo-tectonic event (Kennedy, 1964). The system is made up of four granitic and mafic gneiss lithologic belts. Mafic gneisses are igneous oligoclase, andesine, hornblende, salite, and garnet gneisses with relatively uniform oligoclase, andesine, hornblende, salite, and garnet compositions (Holm, 1974).

Petrography is the detailed study of rocks; the description in the field, macroscopic and microscopic analysis of minerals under a petrographic microscope. Mechanical Properties are physical properties that a material exhibits upon the application of forces. Most of the previous studies conducted in the Dahomeyide basement terrane focused on the orthogneisses without considering the significance of the granites (Attoh et al., 1997). This study highlights on providing detailed information on the structural features of the minerals as wells as highlighting on the petrographic and mechanical properties of the Dahomeyan granitic rocks from the Green Valley and Akrofu localities. The results obtained from this project work will be very vital in knowing the right type of rock and its competences to choose when performing any engineering works. The results obtained from this project work will be useful for future reference and used in engineering investigations. The main aim of this project is to determine the petrographic and mechanical properties of the Dahomeyan granitic rocks in Green Valley and Akrofu. The research helps to determine the mineralogical composition of the rocks; determine the strength and competence of the rocks; and compare rocks from both localities in terms of their mineralogical composition and strength properties.

2. GEOLOGIC SETTINGS

The Pan African orogenic Dahomeyide belt formed as a result of the continental collision between the eastern margin of the West African Craton (WAC) and the Benin-Nigerian shield (Figure 1a) after the closure of a subduction event around 0.6 Ga years ago (Caby, 1989; Affaton et al., 1991; Ganade de Araujo et al., 2016). The belt has a well-organized

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orogenic architecture with its main three litho-structural zones i. e., from West to East, the external zone, the suture zone and the internal zone or the Benino-Nigerian geological province (Affaton et al., 1991). These zones are separated by thrust contacts and each one constitutes a thrust sheet (Figure 1b). The internal nappes mainly composed of granitic gneiss and migmatitic rocks; (2) the suture zone (intermediate nappes) made up of SSW–NNE elongated eclogites, pyroxenites, metanorites and granulite bodies parallel to the Pan African structural trend; and (3) the external nappes interpreted as the deformed edge of the WAC and it covers rocks comprising the Buem and Atacora (Togo) Structural Units.

The deformed edge of the WAC constitutes the basement Dahomeyan external unit (basement complex) and made up of meta granites, granodiorites, amphibolites and varied gneisses known in Ghana as Ho gneisses, and in Togo as Kara and Palime-Amlame gneisses (Affaton et al., 1991; Attoh et al., 1997; Agbossoumonde et al., 2007). Previous works interpreted these rocks as remobilized rocks derived from partial melting of thickened Archean lower crust during the Eburnean Orogeny at ~2.1 Ga (Agbossoumonde et al., 2007). Deformed alkaline rocks and carbonatite occur at the sole thrust of the suture zone and the basement complex (Nude et al., 2009). The Buem Structural Unit (BSU) consists of succession of massive arkoses and a thick pile of shales, siltstones, mudstones interbedded with chert, limestones, mafic and felsic volcanics as well as serpentinite ultramafic rocks. It is regarded as the westernmost unit of the Dahomeyide external nappes and thrusts to west on the Volta Basin sediments, which corresponds to the foreland of the belt.

Akrofu is about 10km from Ho, the Volta regional capital. It has Sokode to the southwest, Klefe Ziavi and Hlefi to the southeast, Wegbe Kplaime to the North West and Bame to the North East. The coordinates of Akrofu (Figure 2) is 6^0 38^1N and is 0^0 23^1E (Dzathor, 1998). Akrofu is made up of two major communities: Xeviwofe and Agove with Xeviwofe being the seat of the Fiaga (Paramount Chief). There are other settler villages such as Dzebukope, Kpetorkope, etc. as part of Akrofu's traditional setup (Dzathor, 1998). Green valley is located under the Adaklu district (Figure 2) which forms part of the 18 of municipalities and district in the Volta region. Green Valley is geographically positioned in the centre of the District. It is located in the southern part of the Volta Region and lies within Longitudes 06°41'1N and 6.68361°S and Latitudes 00°20'1W and 0.33361°E (Dzathor, 1998). The vast land area of Green Valley is a great asset to the people of Adaklu. It shares boundaries with Ho Municipal to the north, Central Tongu District to the south, Agotime-Ziope District to the east and to the west with Ho West District. Green Valley forms one of the seventy-five communities of the Adaklu District. (Dzathor, 1998).

3. Materials and Methodology

3.1 Analysis of Thin Section and Laboratory Test Data

Thin sections were prepared to enable the minerals well identified microscopically. The experiments (both petrographic and mechanical) were prepared at the Kwame Nkrumah University of Science and Technology (KNUST) Geological Engineering Laboratory and KNUST Civil Engineering Laboratory in Kumasi-Ghana between April and July, 2021. The rock samples are cut into smaller slabs using a diamond bladed machine. The cut slabs are polished and placed on a thin wet glass slide, which is then trimmed down to a thickness of 30μm. The petrographic microscope is used to analyze the thin parts, which helps with the identification and thorough analysis of constituent minerals and textures. Thin sections are produced and examined using an optical polarizing microscope for petrologic and textural analyses. Textural descriptions include modal estimation of minerals, mineral grain size, grain form, grain orientation, mineral inclusions and alterations, crystallization, noticing of overgrowth and intergrowth textures, and mineral associations.

3.1.1 Apparatus

Rock cutting machine, cutting and polishing machine (Hillquist thin section machine), grinding machine, epoxy, abrasives (sandpaper of grades 60-1000), glass slides, silicon powder and an optical microscope (Leica Polarizing microscope).

3.1.2 Procedure

The thin section was first viewed in plane polarized light (PPL) to identify the colour, pleochroism, relief, cleavage, and crystal habit. The birefringence, interference colours and extinction were viewed under crossed polar. The data obtained from the petrographic study under the microscope were compiled. The data was interpreted using the Michel-Levy chart and the Elsevier's Mineral and Rock table. Literatures were acquired and reviewed to have fair knowledge of the geology of the area. Various articles and reports provided information on the petrology of the Dahomeyan basement rocks. Appreciable and sizeable rock samples were collected from Akrofu and Green Valley localities at the Volta Region in Ghana. The sampled rocks were sent to the Geological Engineering Laboratory at Kwame Nkrumah University of Science and Technology (KNUST), Kumasi for the thin section preparation and microscopic analyses, whilst the samples sent to the Civil Lab were for the Unconfined Compressive Strength (UCS).

3.2 Laboratory Testing of Rock Samples Using Schmidt Hammer

The purpose for preforming the various strength test was to find out how strong the intact rocks of the rock units are and also how much load they can take before they deform. The Schmidt Hammer test was aimed at obtaining the maximum axial compressive stress the rock sample can bear under zero confining stresses. Schmidt hammer (Figure 3) is a device used to determine the elastic properties or strength of a rock or concrete, specifically surface hardness and penetration resistance. Ernst Schmidt invented it in 1948 and the hammer measures the rebound of a spring-loaded mass striking a sample's surface (Goudie et al., 2006). The test hammer strikes the rock with a predetermined amount of force. Its rebound is affected by the hardness of the rock and is measured by test equipment. The rebound value can be used to calculate the compressive strength of a rock using a conversion chart. When performing the test, hold the hammer at right angles to the surface, which should be flat and smooth. The rebound reading will be affected by the hammer's orientation, and when used oriented upward, gravity will increase the mass's rebound distance, and vice versa for a test performed on the floor slab. Schmidt hammer measurements are taken on a scale ranging from 10 to 100 (Goudie et al., 2006).

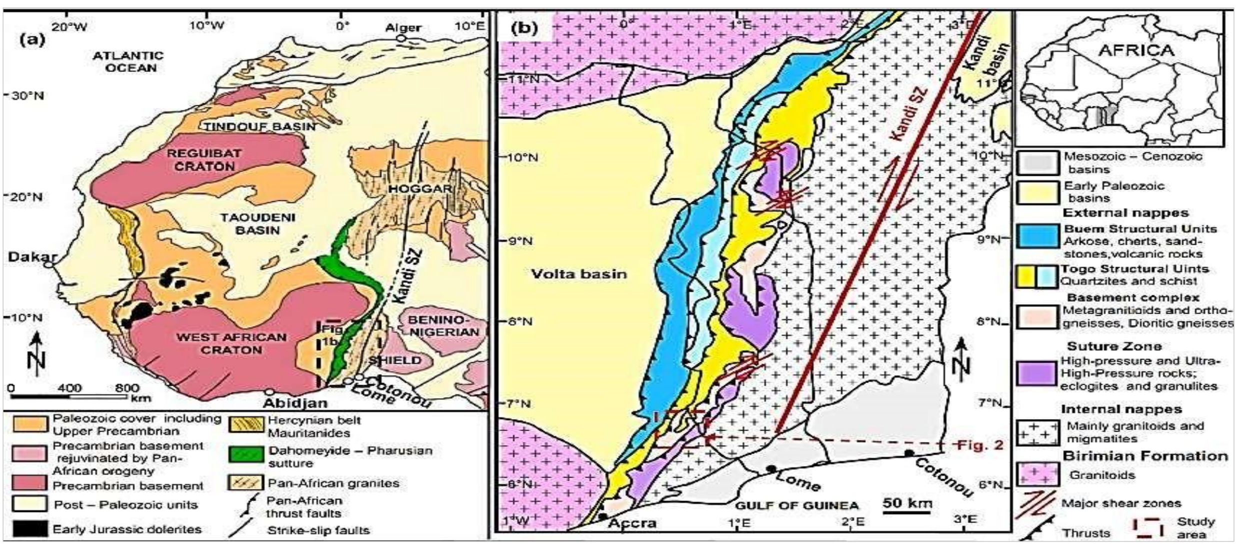

Figure 1: A map of the West African Craton showing location of the Dahomeyide Orogenic Belt (Modified after Ganade de Araujo et al., 2016)

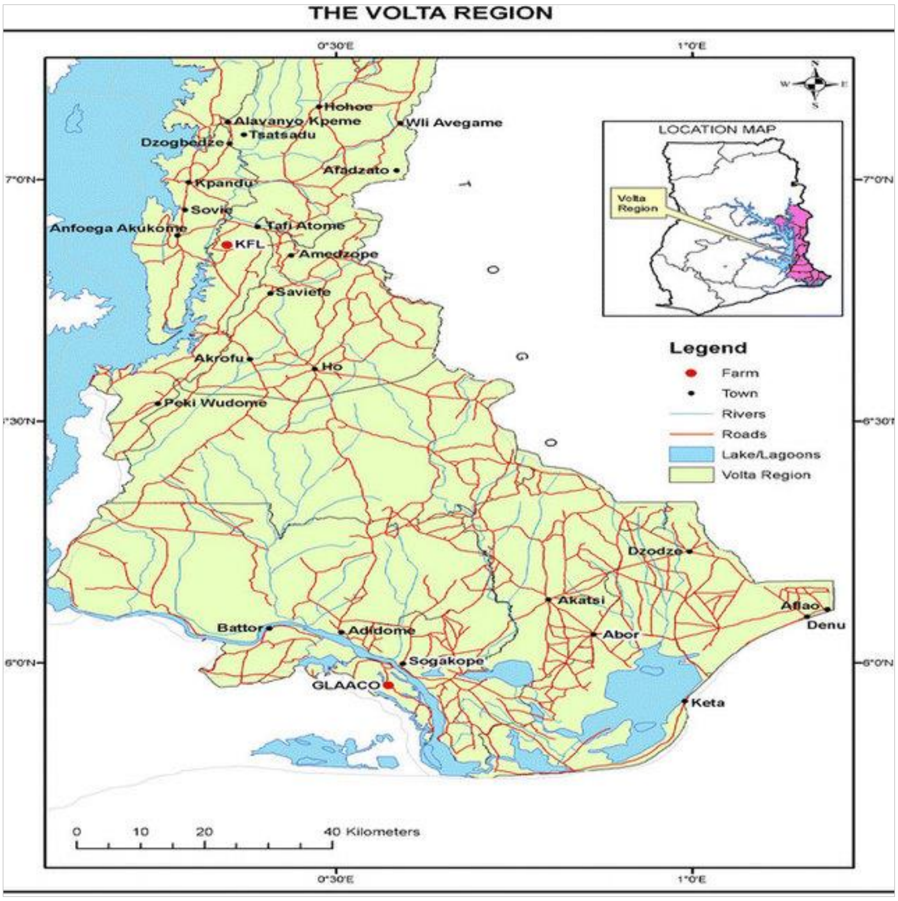

Figure 2: A map of Volta Region locating Akrofu and Green Valley

3.2.1 Procedure of Using the Schmidt Hammer

- A clean, dry, and smooth rock surface was chosen;
- The point of impact was 20mm from any of the rock's edges;
- Measurements were taken with the rebound hammer at a right angle to the rock's surface;
- The test was performed vertically upwards on horizontal surfaces and horizontally on vertical surfaces, yielding different rebound numbers for the same rock in each case;
- The Schmidt hammer plunger was pressed against the rock surface, and the hammer's spring-controlled mass rebounded;
- The rebound values were read off the rebound hammer's graduated scale, as well as the compressive strength directly from the graph provided.

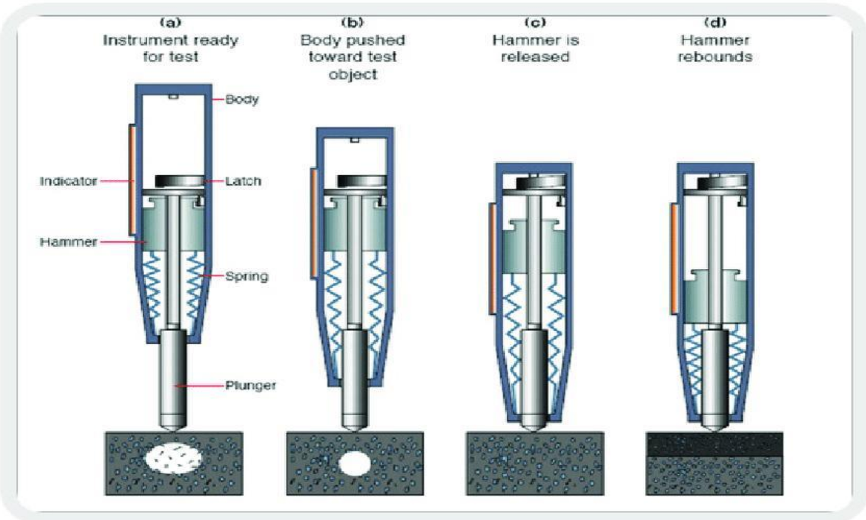

Figure 3: Procedure involved in using the Schmidt hammer

4. RESULTS AND DISCUSSIONS

4.1 Results

4.1.1 Macroscopic Description of Green Valley and Akrofu Rock Samples

The rock sample is grey in colour, coarse-grained metamorphosed rock showing compositional banding and indistinct cleavage. The minerals appear in bands with the darker bands having more mafic minerals (Fig. 4A) such as biotite (those containing more magnesium and iron) and the lighter bands having more felsic minerals such as quartz, muscovite and feldspar. Akrofu rock sample is medium to coarse-grained rock that is among the most abundant intrusive igneous rocks. It contains quartz and is distinguished from granite by it having more plagioclase felspar than orthoclase felspar. Hornblende, biotite, quartz and minor amount of muscovite mica are mineral observed in the rock sample (Figure 4B).

4.1.2 Microscopic Analysis

The thin sections prepared for both Akrofu and Green Valley rock samples were viewed under the petrographic microscope in both PPL and XPL. The results were recorded in Tables 1 and 2.

Figure 4: Megascopic descriptions of rocks of coarse-grained minerals of feldspars, quartz, biotite and hornblende sampled at: (A) Green Valley; and (B) Akrofu in Volta Region of Ghana.

Table 1: Modal Composition of the Biotite Granitic Gneiss from Green Valley

Mode	Volume (%)	Characteristics
Quartz	30	Medium grained, subhedral to anhedral habit, recrystallization of quartz
Orthoclase	25	Subhedral to euhedral habit, very coarse-grained, one cleavage plane
Plagioclase	20	Subhedral to euhedral habit, one cleavage plane, shows lamellar twinning. Some are recrystallized
Biotite	10	Irregular flakes and elongated plates, brown to pale brown in PPL and dark brown colour in XPL (pleochroic)
Amphibole	8	Sub- to euhedral, two cleavages planes, cleavages at 120 and 60 degrees
Muscovite	5	Subhedral to euhedral habit, parallel cleavage
Sericite	2	Alteration from the feldspars

Table 2: Modal Composition of the Granodiorite from Akrofu

Mode	Volume (%)	Characteristics
Quartz	35	Subhedral to anhedral habit, undulose extinction due to deformation and recrystallization of quartz
Plagioclase	25	Subhedral to euhedral habit, one cleavage plane
Orthoclase	16	Subhedral to euhedral habit, coarse-grained, one cleavage
Biotite	10	plane
Amphibole	5	Irregular flakes and elongated plates, brown to pale brown in PPL and dark brown colour in XPL (pleochroic), the mineral shows some rate of alteration and shearing
Muscovite	7	Sub- to euhedral, two cleavages planes, cleavages at 120 and 60 degrees
Sericite	2	Subhedral to euhedral habit, parallel cleavage Alteration from the feldspars

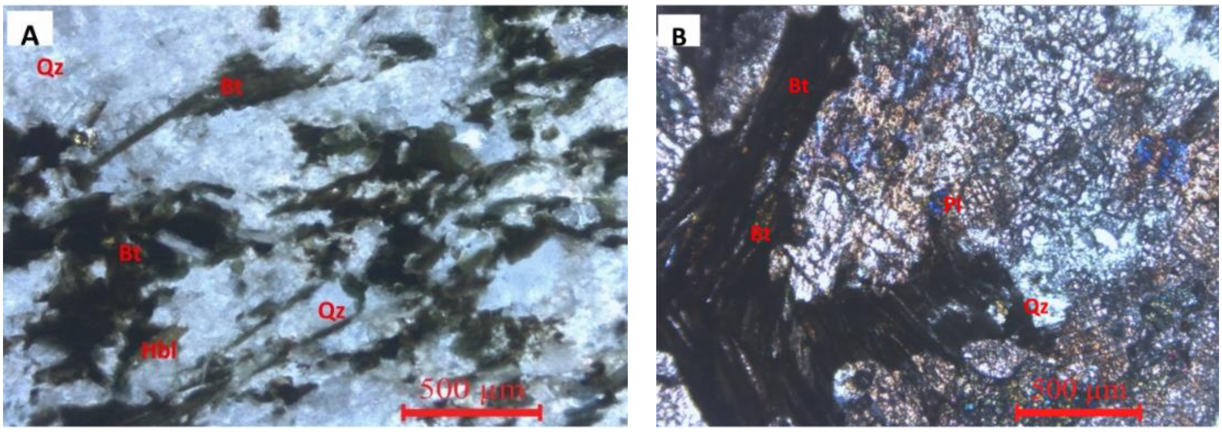

Figure 5: Photomicrograph of representative sample of: (A) gneiss consisting of phenocrysts of Biotite (Bt), Quartz (Qtz), Hornblende (Hbl) at Green Valley; (B) granodiorite consisting of phenocrysts of Plagioclase (Pl), Quartz (Qtz), Biotite (Bt), in XPL at Akrofu

4.1.3 Strength Properties Data Analysis

The Table 3 below is the result obtained after conducting the Schmidt hammer test for both rock samples from Akrofu and Green Valley.

The strength parameters of the rock are classified using Bieniawski classification of strength of intact rock (Bieniawski, 1998). The unconfined compressive strength tests classification scheme is shown in Table 4 below.

Table 3: Schmidt Hammer Test for Akrofu and Green Valley Rock Samples

SAMPLE ID	REBOUND (H)	UCS (MPa)	SAMPLE ID	REBOUND (H)	UCS (MPa)
AKROFU	22	12.00	GREEN VALLEY	38	40
	21	11.00		36	36
	36	36.00		38	40
	21	11.00		33	33
	36	36.00		34	34
	35	35.00		38	40
	MEAN	**23.50**		**MEAN**	**37.17**

Table 4: Classification of Strength of Intact Rock (Bieniawski, 1998)

Qualitative Description	Compressive Strength (MPa)	Point Load Strength (MPa)	Ratings
Extremely Strong	>250	8	15
Very Strong	100 – 200	4 – 8	12
Strong	50 – 100	2 – 4	7
Medium Strong	25 – 50	1 – 2	4
Weak	5 – 25	Use of UCS preferred	2
Very Weak	1 – 5	-do-	1
Extremely Weak	< 1	-do-	Q

5. Discussion of Results

5.1 Macroscopic Discussion on Both Green Valley and Akrofu Rock Samples

The Green Valley rock sample is grey in colour, coarse-grained metamorphosed rock showing compositional banding with a clear cleavage. The minerals appear in bands with the darker bands having more mafic minerals such as biotite (those containing more magnesium and iron) and the lighter bands having more felsic minerals such as quartz, muscovite and feldspar (containing more of sodium and potassium). The rock has distinct banding due to the appearance of the darker minerals in bands and is distinguished from other rocks such as schist by a well-developed gneissosity. The Akrofu rock sample on the other hand, is medium to coarse-grained rock that is among the most abundant intrusive igneous rocks. It contains quartz and is distinguished from granite by having more plagioclase feldspar than orthoclase feldspar. Hornblende, biotite, quartz and minor amount of muscovite mica are minerals observed in the rock sample. This rock is intrusive igneous rock that have phaneritic texture (i.e. the crystals are so coarse that individual minerals can be distinguished with the naked eye). The grain sizes are visible to the naked eye and its formation is as a result of slow cooling crystallization below Earth's surface.

5.2 Microscopic Discussion on Both Akrofu and Green Valley Rock Samples

The rocks are different from each other but they both show some similar mineralogical content in that minerals like biotite, quartz and hornblende are present in both Akrofu and Green Valley rocks. The Akrofu rocks are characterized by dark biotite minerals arranged in bands giving the rock a coarse texture. The rock has minor content of muscovite giving it a light grey colour and mostly composed of feldspars and quartz. The quartz has hypidiomorphic texture which means some grains of some mineral species are anhedral to euhedral. The potash feldspars are present as subhedral to anhedral microcline crystals and occur as small interstitial crystals or enclosed in plagioclases. The K-feldspar undergoes an altered twinning. Hornblende grains are intertwined with the plagioclase. Crystals are evenly distributed and slightly fractured. Deformation features and kinematic indicators are observed on the Akrofu rock under the microscope and these are the fractures within the grains. The Akrofu granitoid is said to be a granodiorite with regards to its mineralogical composition (Table 2, Figure 5B).

The Green Valley rock sample shows assemblage of hornblende, biotite, quartz, plagioclase feldspar minerals as well as brown to grey phenocrysts of K-feldspars. The quartz has a well-developed distinctive crystal shape with ophitic texture and undergoes undulose extinction. Plagioclase undergoes twinning with tabular crystals. It displays striations and crystals are in a grouping of matrix. Hornblende has an elongated crystals and excellent cleavage. The rock presents foliations which are formed when the flat or elongate minerals are squeezed by pressure to become aligned and these foliations are highlighted by alternating biotite aligned in a preferential order. The rock does not preferentially break along the plane of foliation because less than 50 % of the minerals formed during the metamorphism are aligned in thin layers. The presence of foliation in the rock is as a result of the re-alignment of minerals when they were subjected to high temperatures and pressures. The Green Valley gneiss is said to be a biotite gneiss because it contains about 10 % of the rock's mineral composition.

5.3 Discussion on the Strength Properties of Both Akrofu and Green Valley Rocks

From Table 3, the rock sample from Akrofu has a compressive strength of 23.50 MPa which falls within the range of 5 – 25 MPa according to the strength classification of intact rocks (Bieniawski, 1998). The rocks that fall in the range 5 – 25 MPa are classified as weak rocks. From Table 3, the rock sample from Green Valley has a compressive strength of 37.17 MPa which falls within the range of 25 - 50 MPa according to the strength classification of intact rocks (Bieniawski, 1998). The rocks that fall in the range 25 – 50 MPa are classified as medium strong rocks. The rocks under study (i.e. Akrofu and Green valley rocks) failed, when subjected to loads beyond their strength and the failure in the rocks took place under compressive, tension and shear forces at different values. It is however, the unconfined compressive strength, which is taken as the most important index property of rocks. The low values obtained for compressive strength are direct effects of the humid tropical conditions that causes weathering of the rocks at the base of the overburden aided by water.

In addition to weathering, structural defects such as fractures, joints, faults and the mechanical drilling process may tend to introduce micro-pores or fractures in the samples thereby leading to a decrease in the strength and modulus of these rocks. The rocks are extensively used in materials for construction. They are characterized by very high crushing (compressive) strength and hence can be easily trusted in most of construction works. The Green Valley rock does not split along the plane of weakness like most other metamorphic rocks and this allow contractors to use it as a crushed stone in road construction. They can be used as building material such as flooring, facing stones on building and also as an architectural stone. On the other hand, the Akrofu rock sample is typically impervious and hard, and forms very strong foundations for most civil engineering works. They are often used as crush stones for road building, construction material, building facade and paving, and as an ornamental stone.

6. Conclusion

The Dahomeyan rocks from Akrofu and Green Valley are classified to be granodiorite and biotite granitic gneiss respectively. From the petrographic studies, granodiorite was characterized by dark biotite minerals arranged in bands giving the rock its foliation and a coarse texture. The rock contains quartz and is distinguished from granite by it having more plagioclase feldspar than orthoclase feldspar. Hornblende, biotite, quartz and minor amount of muscovite mica are minerals observed in the rock sample. It has minor content of muscovite giving it a light grey color and mostly composed of feldspars, and quartz. On the other hand, the gneiss assemblage include hornblende, biotite, quartz, plagioclase feldspar minerals as well as brown to grey coarse-grained phenocrysts of K-feldspars. The structures observed within the rock sample are fractures and foliations.

The Green Valley contains biotite aligned in a preferential order which indicates the presence of foliations. The foliations are highlighted by alternating dark mafic mineral (biotite), clear quartz and feldspar bands and the presence of foliation indicates that the rock has undergone some form of metamorphism. On the other hand, the structures within the grains of the rock from Akrofu are said to be fractured and these are as a result of weathering processes and climatological changes. The strength properties of the rocks were based on the classification of Bieniawski, 1998. The Akrofu rock is classified to be a weak rock with compressive strength of 23.50 MPa whiles the Green Valley is classified to be a medium strengthened rock with a compressive strength of 37.17 MPa but these low values were as a result of presence of fractures running through the samples as well as weathering process.

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