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**Research Article**

# Geological and Geotechnical Properties of Some Rocks for Ornamental Purposes From Nding – Barkin Ladi, North Central Nigeria

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**Abstract**

This research was conducted to determine the suitability of the rocks within the study area for dimension stone production and possibly decorative purposes of same. This is because the demand for most of the finished products of ornamental rocks in Nigeria is largely met through importation. Concerted efforts were made to determine the different rock units, measure and analyse the structures on the outcrops as well as petrographic studies to ascertain the mineral composition. Other examinations carried out include the mechanical properties of compressive strength, specific gravity and water absorption. Others include porosity and Polish Stone Value (PSV) tests. Results of this research reveal that the area is basically of four (4) rock units, namely migmatitic granite, granite porphyry, pyroxene granite and granite gneiss and fresh samples of these rock types reveal acceptable colour combinations. Also, the discontinuities which are joints and veins are not closely spaced and trend predominantly in the NE-SW direction. The petrographic studies show majorly the presence of quartz, feldspars (plagioclase/orthoclase) and biotite/muscovite in all the rock types. Results of the mechanical properties of compressive strength range between 161.71 – 176.52 MPa, 2.60 - 2.76 for specific gravity, 0.185% – 0.204% for porosity, 82% – 85% for PSV and 0.17% – 0.35% for water absorption which disclose granite porphyry the excellent rock unit for dimension stone quarry. However, the other rock units could also be harnessed for other ornamental/decorative purposes like garden furniture, benches, and fountains. On the whole, the study area is a potential site for quarry operations.

*Key words:* Dimension stone, Structures analysis, Petrographic studies, Compressive strength, Specific gravity, Porosity.

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## Introduction

Dimension stone is defined as rock that is removed from its original site to be used with minor alteration (rough stone) and rock that is broken, sawn, and/or ground and polished (cut or dressed stone) for use as building and/or ornamental stone (Howard, 2010). Dimension stones could be boulders called field stones or quarried from the main mass. The latter usually reflects the true colour, relatively fresh and unweathered which makes dressed rocks from quarries more preferred than field stone picked from the surface. Some dressed-stone operations can produce blocks of stone weighing up to about nine tonnes, such large blocks require specialized equipment for extraction and transportation. These rocks are usually selected and neatly cut to definite sizes or shapes, achieved by techniques such as diamond wire saws and careful blasting with a weak explosive. Typical requirements for dimension stones include colour, texture, pattern and surface finish (Egesi and Tse, 2011). Other essential selection criteria are physical properties of strength, porosity estimation, aesthetic value test and oxidation (Ramadan, Isiaka and Chongs, 2017). The knowledge of the geotechnical properties of rocks is important because they play a vital role in the performance of the rocks as construction materials (Ahkil and Venkat, 2015).

The study area is part of the Jos Plateau, specifically within the Ropp complex which covers a roughly triangular area of about 240sq. miles (Falconer 1921), underlain by rocks of the Crystalline Basement and Younger Granite suite. Nding and surrounding areas constitute the study area and it is endowed with an abundance of granitic rock outcrops which will serve as a great advantage to the constructional industries because of the dense nature and hardness of the rocks. Furthermore, these rocks outcrops have not been exploited in any way and could possibly meet the requirements for dimension stone production which in turn would boost local content production within the region and country at large. However, the need to investigate the rock outcrops so as to ascertain their suitability for dimension stone production is pertinent.

### Location and Accessibility

The study area is located in Barkin Ladi Local Government Area of Plateau state, north-central Nigeria. It is bounded by latitudes $9^0 34'29''$N and $9^0 37'48''$N and longitudes $8^0 55'43''$E and $8^0 59'17''$E and encompasses a total area extent of 33 $Km^2$ (Figure 1). It forms part of Naraguta Sheet 168 SE published by the Federal Survey Department of Nigeria.


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The study area is accessible through a good network of road connection linking Nding from the major Barkin Ladi – Mangu road and other untarred roads and footpaths connecting surrounding settlements.

## Aim and Objectives of the Study

The aim of this research is to provide the structural and geotechnical analysis in order to ascertain the suitability of the rocks within the study area for dimension stone production.

The Objectives are as follows:

1. Determine the different rock units and structural disposition within the study area
2. Carry out the petrographic studies on the different rock units
3. Determine their physical and geotechnical properties.

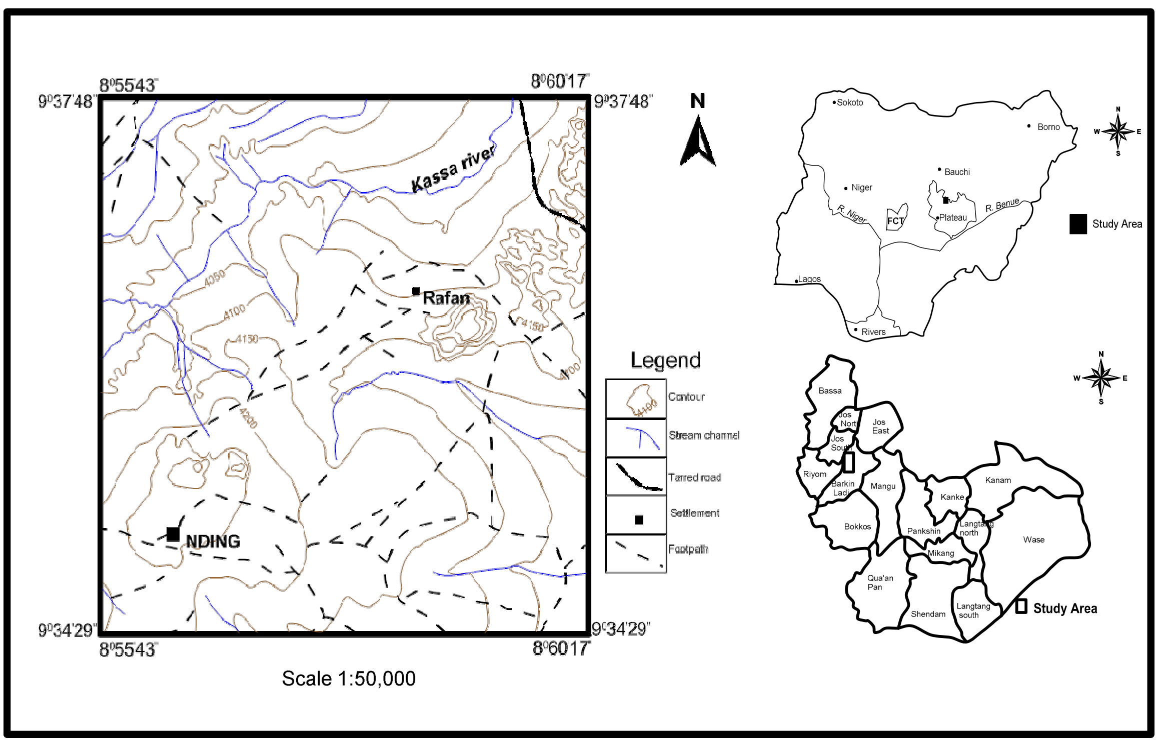


*Figure 1. Location Map of the Study Area*

## Methods of Investigation

### Geological Investigation, Rock sampling and Structural Measurements Procedures

The importance of geological mapping on a local scale cannot be overemphasized as it is usually more detailed. Therefore, intensive geological mapping of the study area was carried out using the topographical map as the base map. Rock outcrops were carefully examined with strike and dip measurements of structures recorded using a compass clinometer. Geological boundaries were generally defined on the basis of major changes in lithology. Also, fresh rock samples were collected and observed in hand specimen and field names assigned to each rock sample in accordance to the minerals observed using a hand lens. A total number of eight (8) fresh rock samples representing different lithologic units within the study area were collected using a sledge/ geological hammer and labelled appropriately. Likewise the coordinates of each point recorded using a Global Positioning system (GPS). Four (4) representative samples were selected for thin sectioning and petrographic studies.

### Petrographic Procedure

Thin sections from the rock samples collected were prepared and studied using the petrographic microscope. This study is recommended to complement the hand-specimen observations. Specifically, thin sections are used to confirm the rock name assigned from macroscopic description of the core and to determine alteration mineralogy. Features of thin section described are the texture, mineral type, morphology others include abundance, overgrowths, zoning, twinning and accessory minerals. Photomicrographs of the thin sections were taken in both cross and plane polarized light.

### Procedure for Geotechnical Properties of Rock Samples Compressive Strength

The strength of the various rock types were determined based on the point load test. This is performed by subjecting a rock specimen to an increasingly concentrated load, until failure occurs by splitting the specimen. It is an effective way of measuring how much load the finished rock product can bear. The process of determining the compressive strength must be done under carefully controlled conditions in order to acquire precise measurements including the equal and opposite forces applied to compress the rock from both top and bottom (Maloney, 2018). The standardized equipment in the point load test is a pair of $60^0$ conical point loading platens installed on a loading frame (Dimitri and William, 2001). The rock samples were compressed one after the other to the point of failure/ permanent deformation, the load/force at failure was recorded for the strength calculation using:


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$CS = \frac{F}{A}$ .. .. .. .. .. .. .. [1] According to Maloney (2018),

where, CS is the Compressive Strength
F is the force or load at point of failure
A is the cross-sectional surface area of the sample.

**Specific Gravity**

The specific gravity for each of the fresh rock samples collected from the field was determined as follows:

Each rock sample was dried in an oven at $105^0$C for 24 hours, cooled and weighed, recorded as ($W_0$)

Each of the same samples were wholly immersed in water for 48 hours and weighed in saturated form as ($W_w$)

Each of the samples still soaked is weighed suspended in water and recorded as ($W_s$).

The specific gravity was calculated for each rock using the formula:

$$SG = \frac{W_0}{Ww - Ws} \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \qquad [2]$$

**Porosity**

The porosity of a rock is the ratio of the volume of voids (pores) to the overall volume of the rock specimen (Dimitri and William, 2001). The value of porosity (n) for the different rock samples were determined in the laboratory and expressed in percent of the volume of each sample using the formula:

$$n = \frac{Ww - Wo}{V} \times 100 \quad .. \quad .. \quad .. \quad .. \quad .. \qquad [3]$$

**Polish Stone Value (PSV) Procedure**

The PSV test was conducted on the rock sample to determine the display of good abrasiveness and yielding of attractive colour tints (Alabi, Oyedepo and Abere, 2017).

The following stages were done to achieve results:

- Fresh rock samples were cut into manageable slab sizes.
- The rock slabs were then pre-polished using abrasives of different size grades starting with the coarsest and finishing with the finest in order to remove uneven surfaces.

- The pre-polished slabs were then immersed into accurate manufactured moulds and then placed on a 'road wheel' of accelerated polishing machine. Slurry abrasive of grade 1:20 were continuously fed through fixed mechanical feeders.
- Flour emery was then loaded on tyre wheel by a spring loader spreader plate with the corn emery directly being fed to the specimen through a feed chute and introducing water at a controlled rate.
- Using a mechanical device, the "tyre-wheel" was then raised and lowered to the "Read wheel". The revolution counter was fitted to 315-325rpm and polishing was allowed for about 25 minutes
- The completed polished slabs are removed from the machine and washed with distilled water to remove contaminants and thereafter dried using pressurized air.
- The dried slabs are viewed under a Vicker-misa microscope fitted with micro hardness testing equipment in order to rate the suitability of the rocks for use as slabs, tiles and monuments.

**Water Absorption Test**

The internal pore characteristics are very important properties of rock. This is because the size, number and the continuity of same through a rock may affect its strength, abrasion resistance, surface texture, specific gravity and the resistance to freezing and thawing and action. Absorption relates to the rock's ability to take in a liquid which is highly dependent on the porosity ratio of the rock volume. Results of this test were achieved though the following steps:

- The fresh rock sample collected was washed to remove particles of dust and then immersed in distilled water at room temperature for 24 hours.
- The sample is taken out of the distilled water and placed in a dry cloth and gently surface dried.
- The same sample was then exposed to atmosphere away from direct sunlight or any other source of heat from at least 10 minutes, until it appears to be surface dried and then weighed as B.
- The same sample is dried in an oven at $110^0$C for 24 hours.
- It was then cooled in a desiccator at room temperature and weighed A.

This was done for each of the different rock samples collected and the water absorption was computed using equation 4, according to Dimitri and Williams (2001).

$$\text{Water Absorption} = \frac{B-A}{A} \times 100 \quad .. \quad .. \quad .. \quad .. \quad .. \quad ..[4]$$

## Presentation of Results

### Results of Geological Investigation, Structural Analysis and Rock Sampling

Four (4) lithologic units were differentiated based on petrology and texture within the study area and they include the migmatitic granite, granite porphyry, pyroxene granite and granite gneiss as shown in Figure 2.

### Migmatitic Granite

The rock occupies about 35% of the study area, mainly occurring in the extreme north western and northern part of the study area (Figure 2), though most of the exposures are limited and the outcrops are of low relief. It has foliations of felsic and mafic minerals which are well developed and a porphyritic mineral grained texture. Structures like veins and joints occur on the outcrops.

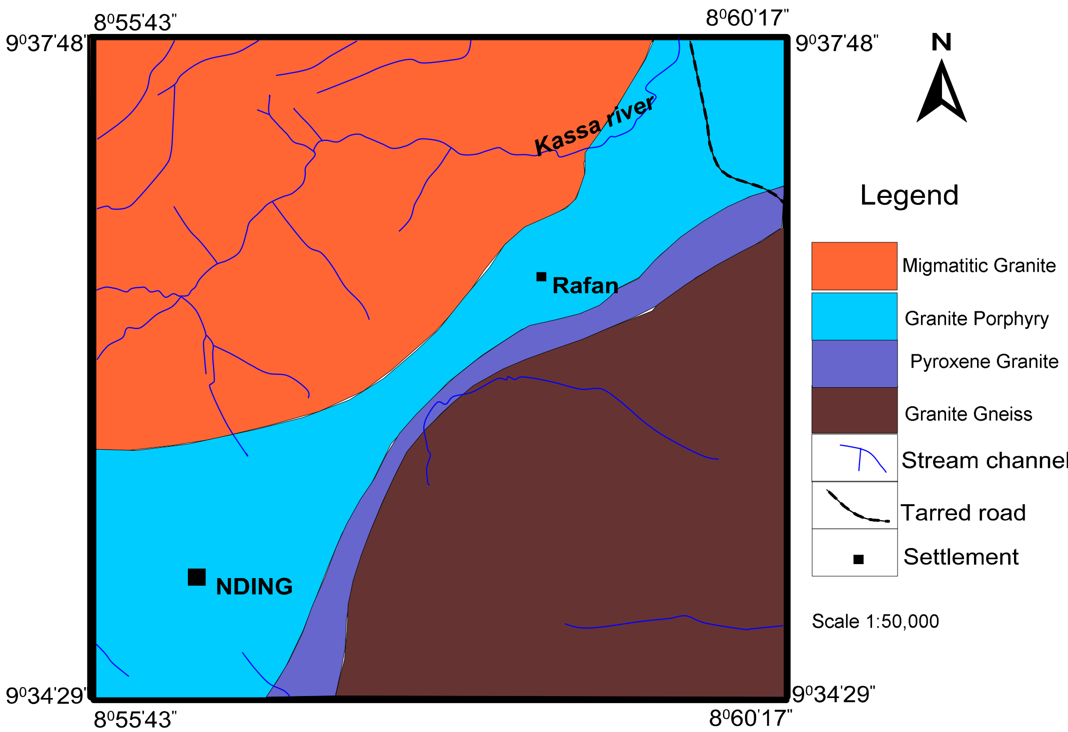


Figure 2. Geological Map of the Study Area

### Granite Gneiss

The composition of this rock corresponds to that of the granite while the texture is transitional between gneiss and granite. It covers about 35% of the study area and occurs mainly in the extreme southern, eastern and south eastern portions of the study


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area (Figure 2). It is generally low lying and obviously part of the Basement Complex suite. The rock is medium grained and generally felsic. Muscovite/biotite, feldspars and quartz are present making up the rock. There is a variation in mineral grains from medium to coarse grains which are randomly oriented. Also, the major structures observed on the outcrop are joints and veins

**Granite Porphyry**

This rock type occupies roughly 20% and is situated in the extreme north eastern, central and south western sections of the study area (Figure 2). This rock type reveals a random orientation of minerals with an apparently porphyritic texture consisting of quartz, hornblende and biotite. Structural features observed on the granite porphyry are joints.

**Pyroxene Granite**

The pyroxene granite covers about 10% of the study area and occurs mainly in the southern, central and eastern section of the study area (Figure 2). The rock is generally greenish in colour and porhyritic in texture. Obviously, pyroxene and biotite are the typical mafic minerals making up this rock type in addition to quartz and feldspars. Joints and veins were also observed and measured on the outcrops.

**Petrographic Analysis**

**Migmatitic Granite**

The mineral grains are anhedral to subhedral in shape and randomly oriented. Muscovite (<5%) is being altered to opaque minerals with zircon as accessory. Others include quartz (40%) and perthite (55%) as shown in Plate 1a and 1b representing the photomicrograph under cross polarized light and plane polarized light respectively.

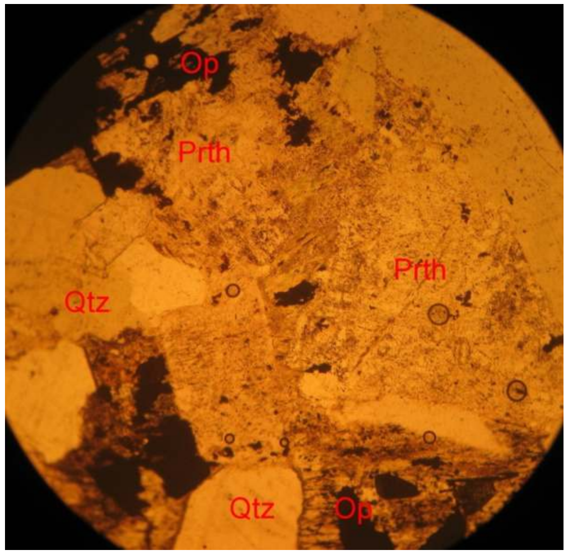


Plate 1a. Micrograph of Mig. Granite XPL Plate 1b. Micrograph of Mig. Granite PPL
Qtz=Quartz; Prth=Perthite; Op=Opaque minerals

**Granite Gneiss**

The petrographic studies of this rock unit shows microcline which is generally characterized by cross hatch twinning and forms as a result of the transformation of monoclinic orthoclase into triclinic microcline. In addition, muscovite and biotite (>5%) partly show altering to chlorite and exhibiting radioactive halos (Plate 2). Quartz is also present making up <42% of the entire minerals. There is a variation in mineral grains from medium to coarse grains which are randomly oriented and mostly anhedral in shape.


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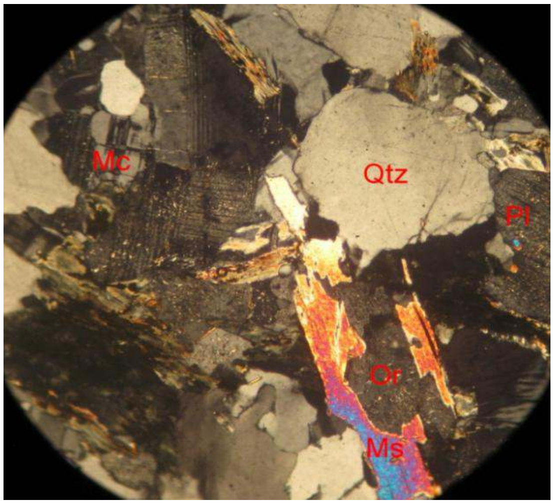


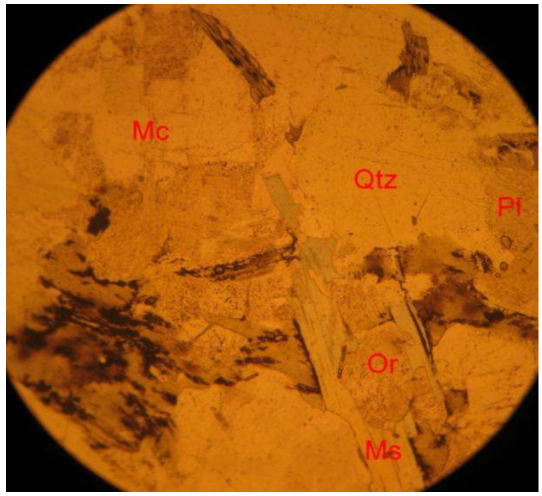
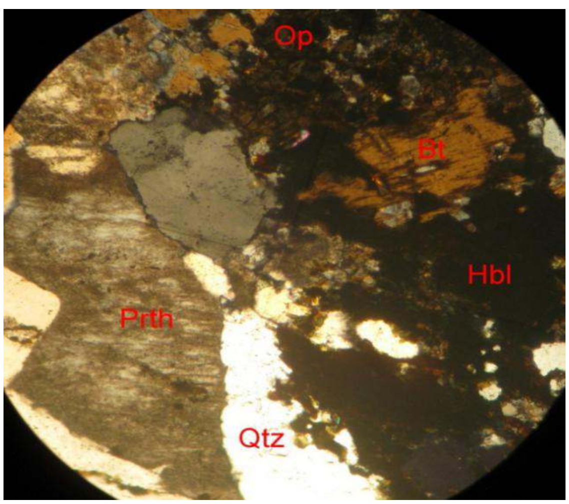




Plate 2a. Micrograph of Granite Gneiss XPL     Plate 2b. Micrograph of Granite Gneiss PPL
Mc=Microcline; Qtz=Quartz; Pl=Plagioclase; Or=Orhtoclase; Ms=Muscovite

**Granite Porphyry**
The petrographic investigation of this rock type reveals a random orientation of minerals with anhedral shape. It is apparently porphyritic in texture consisting of quartz (<35%), perthite (>60%), hornblende (>30%,) and biotite (<20%) . Accessory minerals are opaque and zircon (Plate 3).



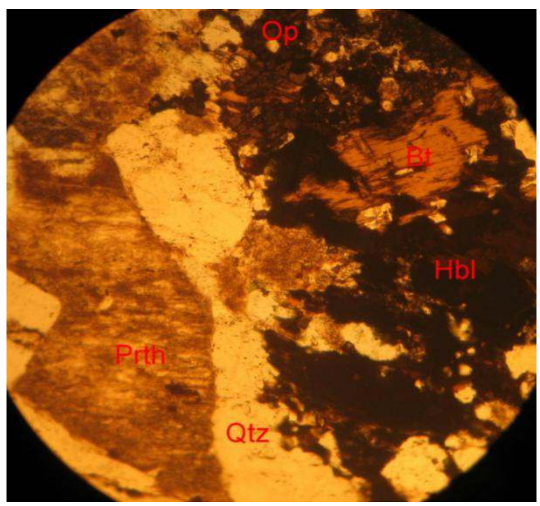




Plate 3a.Micrograph of Granite Porph. XPL     Plate 3b. Micrograph of Granite Porph. PPL Or=Orthoclase; Qtz=Quartz; Pl= Plagioclase; Prth=Perthite; Bt=Biotite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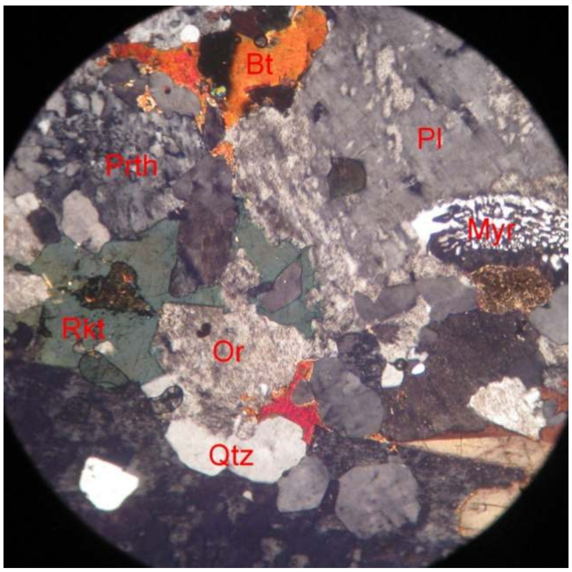
**Pyroxene Granite**

Observations on the basis of petrographic evidence reveal the presence of myrmekite which is a vermicular or wormy intergrowth of quartz in plagioclase and usually formed under metasomatic conditions in conjunction with tectonic deformations. Other minerals observed include quartz (>35%), perthite (<65%), biotite and riebekite together making up <5%. Accessory minerals include opaque minerals and zircon. There is variation in the grain sizes from medium grains to coarse grains; mineral shapes too vary from subhedral to anhedral. Though the quartz grains are rounded (Plate 4).



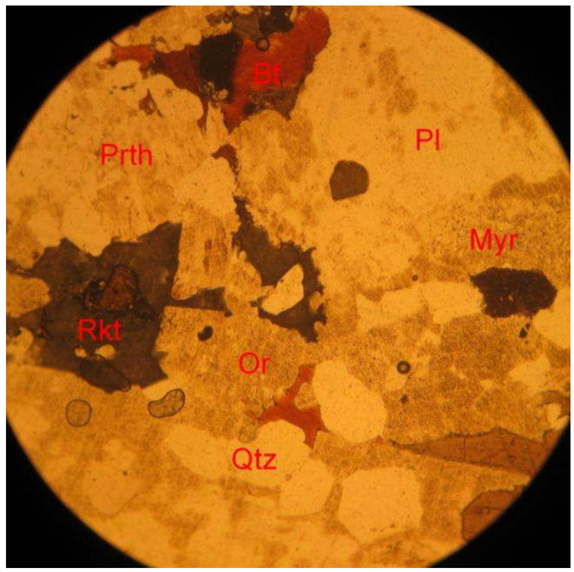




Plate 4a.Micrograph of Pyrox. Granite XPL        Plate 4a.Micrograph of Pyrox. Granite PPL

Rkt=Riebeckite; Myr= Myrmeckite; Or=Orthoclase; Qtz=Quartz; Pl= Plagioclase; Prth=Perthite; Bt=Biotite

**Structural Analysis on Rock Outcrops**

The structures on the outcrops were observed to be well spaced (Plate 5) which will further enhance the production of dimension stones. The analyses of structural measurements in the form of rose diagrams as shown in Figures 3 – 6.


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Plate 5: Veins within the study area

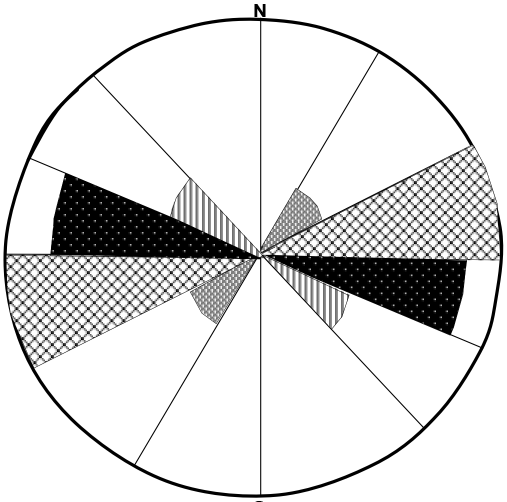


*Figure 3a. Veins on Pyroxene Granite*
Dominant trend: NEE-SWW

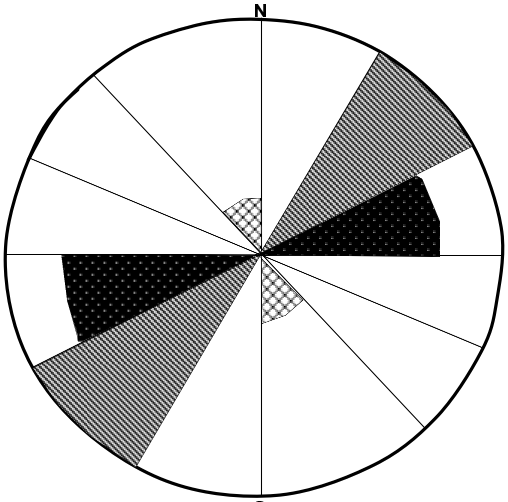


*Figure 3b. Joints on Pyroxene Granite*
Dominant trend: NE-SW

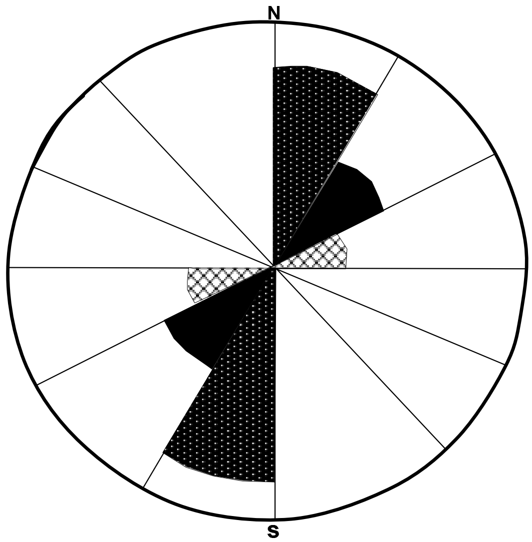


*Figure 4: Joints on Granite Porphyry*
Dominant Trend: NNE-SSW

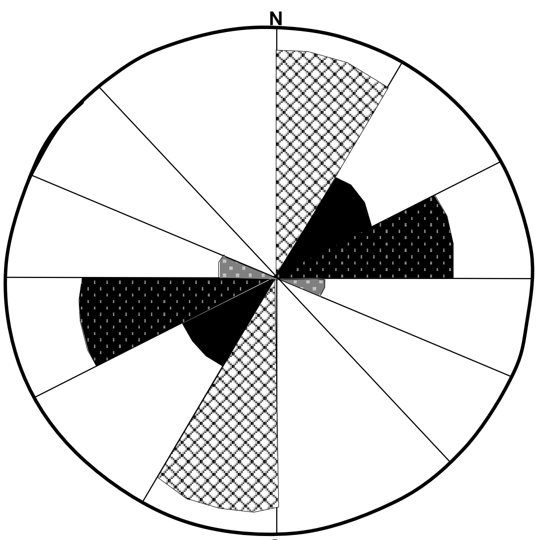


*Figure 5a: Veins on Granite Gneiss*
Dominant Trend: NNE-SSW

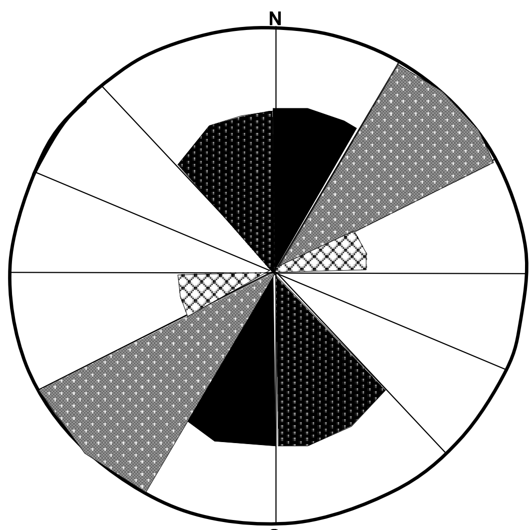


*Figure 5b: Joints on Granite Gneiss*
Dominant Trend: NE-SW


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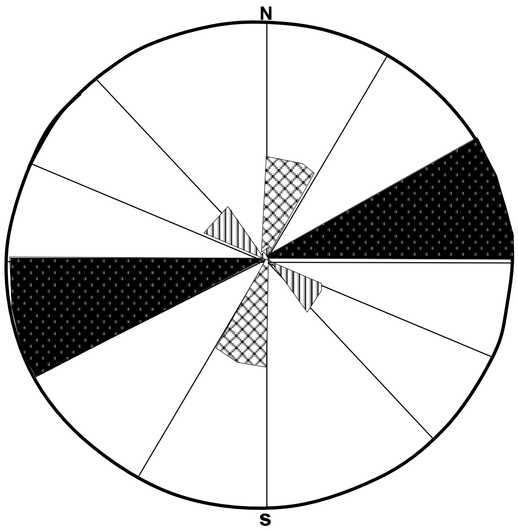


*Figure 6a: Veins on Migmatitic Granite*
Dominant Trend: NEE-SWW

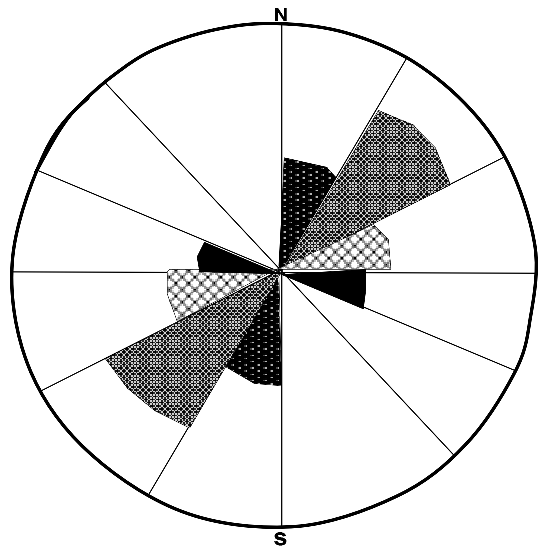


*Figure 6b: Joints on Migmatitic Granite*
Dominant Trend: NE-SW

**Geotechnical Properties of Rock types**

Results of the geotechnical parameters of the different rock units within the study area are summarized in Table 1.

## Discussion of Results

The petrographic studies did reveal the mineralogical composition and the true nomenclature of the rock units. All the rock types are basically granitic, composed majorly of quartz, feldspars and muscovite/biotite. The presence of feldspars in most of the samples is to a disadvantage because feldspars may easily weather to clay which may make the samples not ideal in dimension stone production. However, considering the extent to which the feldspars have been altered, it was interesting to have observed from the photomicrographs (Plates 1, 2, 3 and 4) that the alterations are minor and will be harmless and probably even add value to the eventual polished rock surface. Therefore on this basis, all the samples examined are viable for dimension stone production and/or aggregates for other construction purposes.

The importance of structures on rock outcrops cannot be overemphasized in dimension stone production owing to the fact that they determine the quarry method. The structural analyses and observations within the study area reveal that most of the structures are isotropic, consisting of similar structures trending predominantly in the


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Table 1. Results of Geotechnical Analyses of Rock types

| Rock Type | Compressive Strength (MPa) | Specific Gravity | Porosity (%) | Water Absorption (%) | Polish Stone Value (%) | Comment |
|---|---|---|---|---|---|---|
| Migmatitic Granite | 165.82 | 2.61 | 0.204 | 0.35 | 84 | Good for decorative and construction stone production |
| Granite Gneiss | 161.71 | 2.60 | 0.198 | 0.32 | 82 | Good for decorative and construction stone production |
| Granite Porphyry | 176.52 | 2.76 | 0.185 | 0.17 | 85 | Excellent for dimension stone quarry |
| Pyroxene Granite | 167.28 | 2.64 | 0.197 | 0.23 | 83 | Good for decorative and construction stone production |
| ASTM Standard Requirement for dimension stone | Minimum of 131MPa (ASTM C170 – 06) | Allowable range 2.00-3.00 (ASTM C 97/C97M -18) | 1.0-2.0% (Broch and Franklin, 1972 in Alabi, Oyedepo and Abere, 2017) | Maximum allowable range 0.20-12% (ASTM C97/C97 M-18) | | |

NE-SW direction (Figures 3, 4, 5 and 6); also, the structures are not closely spaced. These properties combined together will allow for development along the three directions of width, length and depth which is ideal for dimension stone production. On the other hand, the presence of quartz veins (Plate 5) on most of the outcrops are objectionable because they would interrupt the uniformity and continuity of the dimension stone blocks.

The geotechnical results of rock samples (Table 1) within the study area display that the compressive strength of granite porphyry is highest with the value of 176.52MPa and a higher compressive strength indicates that the stone can withstand a higher crushing load (CE Centre, 2020). This makes the granite porphyry most appropriate for the purpose of dimension stone within the area under investigation. Although, the compressive strength recorded for the other rock outcrops (migmatitic granite – 165.82MPa; granite gneiss – 161.71MPa and pyroxene granite – 167.28MPa) still satisfy the ASTM C170-06 minimum standard requirement for granite in respect of dimension stone of 131MPa. Therefore, same could be exploited and used for other decorative purposes like garden furniture, benches, fountains, kitchen countertops and so on.

The results of specific gravity of the rocks tested within the study area displayed on Table 1 shows that granite porphyry has the highest density of 2.76 which is beneficial for dimension stone production and subsequent polishing. Furthermore, the specific gravity of 2.60, 2.61 and 2.64 for granite gneiss, migmatitic gneiss and pyroxene granite respectively within the study area also satisfy the ASTM C97/C97M-18 standard range of 2.0 -3.0. This can also be translated to durability, because in most cases a high-density rock is probably harder, less porous, and stronger (CE Centre, 2020).

The porosity of the rock samples was also determined and in respect to this factor, the granite porphyry had the lowest porosity value of 0.185% while the migmatitic gneiss had the highest value of 0.204% as shown in Table 1. This is reflected in the water absorption values showing a direct relationship with porosity revealing low water absorption value of 0.17% for granite porphyry and the highest value of 0.35% against migmatitic gneiss. However, the porosity and water absorption values are generally low and agree with the standard requirements captured in Table 1, implying that water would be less able to penetrate and cause damage.

Rock Polishing was carried out on the samples collected basically to appreciate the beauty of the rock surface. Results of the Polish Stone Value (PSV) for all the rock samples representing the area are considered good with the highest value of 85% for granite porphyry and least value of 82% for granite gneiss (Table 1)

## Conclusion and Recommendation

The following conclusions are made based of the findings from this research:

- Based on the structural and technical properties of the four (4) rock types established, the granite porphyry outcrop is particularly suitable because it possesses excellent properties that would permit it to be exploited as dimension blocks or slabs which could be finished as wall/floor tiles, countertops and monuments.

The other three (3) rock outcrops (migmatitic granite, granite gneiss and pyroxene granite) can also be harnessed as smaller blocks (cut – to - size) for subsequent polishing to be used as decorative/ornamental pieces and for other types of building applications like landscaping, walkways, moulding etc.

It is therefore recommended that the granitic outcrops in Nding be considered for both dimension stone production as well as aggregates for other construction purposes.

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