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# MODIFIED VOLUMETRIC JOINT COUNT TO CHECK FOR SUITABILITY OF GRANITE OUTCROPS FOR DIMENSION STONE PRODUCTION

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**Abstract**

This study compares the characterization of fractures of some granite outcrops in Southwestern Nigeria. Some geometrical properties of discontinuity (orientation, persistence, aperture, infilling and spacing) were evaluated. On the granite studied, most of the mapped joints have orientations that fall within 84°/020° and 86°/300°. These patterns are compatible with the regional fracturing, which is predominantly shaped by NW-SE, NE-SW, NNE-SSW, ENE-WSW and WNW-ESE structure of tectonic origin. The XX type joint persistence is dominant while RR type is in minority. Closed aperture was observed at Ore, Awo and Ikole granite outcrops. The infilling materials are mica and quartz; their percentages are constant for all the outcrops studied. The modified volumetric joint count ranges from 0.67 $m^{-1}$ to 1.24 $m^{-1}$ and the average spacing of all sets varies from 1.62 m to 2.50 m. Fracture network characterization as carried out revealed that, for an outcrop to be economically suitable for dimension stone production, the modified volumetric joint count should not be above 1.7 $m^{-1}$ and must be at least 'good' rock according to conventional rock mass classification. Numerical modeling of block size distributions of selected granites in Southwestern Nigeria was done using AutoCADTM 3D.

Keywords: Granite, Dimension stone, Volumetric joint count, Economical exploitation.

## 1. Introduction

Identification of suitable location of good quality granite rock outcrops for aggregates and/ or dimension stone blocks production is one of the major problems confronting engineers in most tropical countries like Nigeria. The

## Nomencalture

| | |
|---|---|
| $J_a$ | Joint Alteration |
| $J_n$ | Joint Set Number |
| $J_r$ | Joint Roughness |
| $J_v$ | Modified Volumetric Joint curve |
| $L$ | Length of scanline |
| $N$ | Number of joint set |
| $S$ | True spacing |

## Abbreviations

| | |
|---|---|
| 3D | 3 Dimensional |
| DD | Discontinuous between fracture |
| DX | Discontinuous in Curve |
| ENE | East North East |
| ESE | East South East |
| GSI | Geological Strength Index |
| NE | North East |
| NW | North west |
| RMR | Rock Mass Rating |
| ROD | Rock Quality Designation |
| RR | Discontinuous Joint |
| RX | Discontinuous in Rock and Fracture |
| SE | South East |
| SW | South west |
| UCS | Uniaxial Compressive Strength |
| WNW | West North West |
| WSW | West South West |
| XX | Continuous Joint |

present technology and mechanization used in extracting and processing granite in Nigeria measures up to the most advanced countries in the world. Industrial processing of granites requires large block size, and the large block size yield is controlled by the natural fracture pattern of the outcrops. According to Brandy and Brown [1], engineering properties such as cavability, fragmentation characteristics and rock mass permeability also vary with discontinuity spacing. Discontinuity spacing is one of the important parameters in describing the quality of a complete rock mass. According to Tomasic [2] and Sonnez et al. [3], several researchers have worked on the fracture patterns of rock mass to evaluate the possibility of obtaining appropriate block size in commercial quantity. The geometrical properties of joints and their networks that can be measured is an important factor for identifying suitability of rock mass for dimension stones production.

Guohua and Xing [4] noticed that joints are the most common and generally the most geotechnically significant structural features in rocks. Bell [5] stated that joints are breaks of geological origin along which there has been no visible displacement, and can also be described as fractures along which little or no displacement has occurred and is present within all types of rocks. At the surface, joints may open as a consequence of stress release and weathering. A group of joints which run parallel to each other is termed a joint set, whilst two or more joint sets which intersect at a more or less constant angle are referred to as a joint system. If joints are planar and parallel or sub-parallel, they are described as systematic. Conversely, when they are irregular they are termed non-systematic. If one set of joints is dominant, then these joints are known as primary joints, the other set of joints being termed secondary. There are several ways of joint formation and systematic sets can be distinguished from non-systematic sets when recording discontinuities in the field Bell [5]. It should be noted that a complete description of joints is difficult because of their three-dimensional nature and their limited exposure in outcrops [6].

The characteristics of individual joints such as orientation, trace length or size, aperture, planarity, roughness, surface morphology and location are used in classification of joints. Joint trace length is one of the most important parameters for evaluating the geomechanical properties of rock mass and these have been studied by many researchers [7, 8].

In fracture network characterization, it was observed that the density and persistence of fractures are critical in determining the in-situ block size distribution of granite outcrop [9]. For an outcrop to produce commercial block, it is recommended that the size must be at least (2.4 m × 1.3 m × 0.7 m). It is also observed that the surface area of a block which is formed by interception of the sub-vertical fracture, for commercial block exploitation, must be at least 2 $m^2$ [10]. The possible methods used for fracture measurement include geophysical acoustic method, drill hole method and surface exposure method which include both hand mapping [11], and more recent application of remote methods such as photogrammetry [12]. A combination of both scanline and window mapping are suitable for dimension stone exploitation where detailed fracture characterization is required for in-situ block size estimation. Blocks are formed by interception of fracture sets. The size of these blocks can be estimated using either empirical methods [6] or numerical methods. Among the empirical methods are volumetric joint counts, joint spacing and block volume methods. In empirical methods the average block size is obtained. The limitation of joint spacing method includes exaggeration of the in-situ block size results and cannot be used where there is occurrence of too many random joints [6].

Persistency of joints is characterized by their termination in accordance with the suggested procedures [13]. Volumetric Joint Count ($J_v$) is a tool proposed for assessing block sizes [14]. The modified volumetric joint count is proposed for use in this study because only the sub-vertical joints were taken into consideration.

The volumetric joint count is given as follows [15]:

$$J_v = \frac{N_1}{L_1} + \frac{N_2}{L_2} + \ldots\ldots \frac{N_n}{L_n} \qquad [\mathrm{m}^{-1}] \tag{1}$$

or

$$J_v = \frac{1}{S_1} + \frac{1}{S_2} + \ldots\ldots + \frac{1}{S_n} \qquad [\mathrm{m}^{-1}] \tag{2}$$

where $S$ is the true spacing, $N$ is the number of joint sets along the scanline, $L$ is the length of scanline and $n$ is the number of joint sets mapped.

When the rock is highly fractured, the formula below is suggested:

$$J_v = \frac{N_x}{L_x} + \frac{N_y}{L_y} + ...... + \frac{N_z}{L_z} \qquad [m^{-1}] \tag{3}$$

where $N_x$, $N_y$ and $N_z$ are number of joint sets counted along the scanline ($L_x$, $L_y$ and $L_z$) perpendicular to each other. But since this condition of perpendicular is hardly met, Eq. (3) is modified to:

$$J_v = \left(\frac{N}{L}\right)^3 \qquad [m^{-3}] \tag{4}$$

where $L$ is the respective scanline length (m).

The use of numerical methods for block size estimation has been done by many authors [16-18], working on the same principle of statistical simulation to obtain the block size distribution. The conditional simulation of point by point occurrences of the fractures along the scanline as well as along the window may be impossible using these programmes. A new approach is introduced in this study using AutoCAD™ to run a simulation of all the fractures as they occur along the scanline or within the window to obtain an explicit estimate of block sizes, assuming continuous jointing.

Modeling is a straightforward task but involves many complexities and compromises. In essence, the key components of any satisfactory modeling approach are data and understanding [19]. The purpose of this model is to create a new approach that maximizes the use of feasibly available data and obtain the block size distribution in the outcrop under consideration.

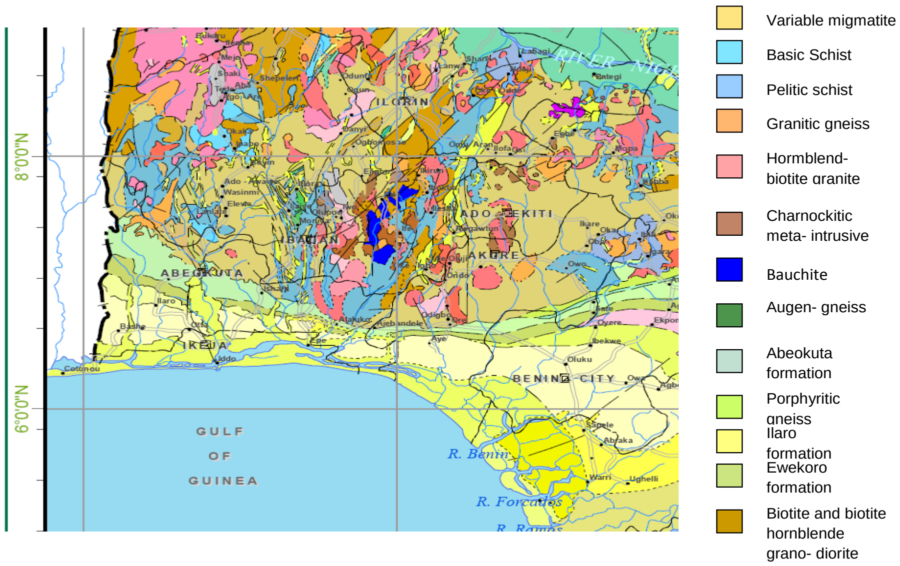
AutoCAD™ has become a standard program for producing technical drawings of all types [20]. Since not all mining operators may have access to FracMan software, incorporating AutoCAD™ to this research work as an alternative to FracMan in determination of block size distribution of an outcrop is considered a useful approach. The advantage of this approach, compared to conventional methods for fracture analysis, is that it provides a better 3D description of the fracture geometry as the entity of position, extent and orientation of single fractures with respect to their surrounding neighbours is conserved.

## 2. Geology of the Studied Area

The study area lies in south western Nigeria. The granite rocks under studies are located in Ekiti State (Ikere, Ewu and Ikole Ekiti), Ondo State (Ore and Supare) and Osun State (Awo). The area is the part of the West African Craton comprising of rocks affected by the late Precambrian to early Paleozoic orogenesis. The Nigerian basement complex extends westwards and is continuous with the Dahomeyan of the Dahomey - Togo - Ghana region. To the east and the south the basement complex is covered by the Mesozoic - Recent sediments of the Dahomey and Anambra Basins.

The Nigerian basement complex comprise predominantly of magmatitic and granitic gneisses; quartzites; slightly migmatised to unmigmatised metasedimentary schists and metaigneous rocks; charnockitic, gabbroic and dioritic rocks; and the member of the Older Granites, granodiorite and syenites. Migmatites are found to be abundant in south western Nigeria.

Ikole Ekiti outcrop is described as granite gneiss, where the granitic material takes the form of indefinite impregnations. Ewu and Awo outcrops belong to charnockitic rocks which composed of three main components which may be observed as a single outcrop. They occur as discrete individuals bodies in the gneiss complex. The charnockites are composed of quartz, alkali feldspar, plagioclase, orthopyroxene, clinopyroxene, hornblende, biotite and accessory amount of apatite, zircon and allanite. Randomly oriented inclusions of various rock types occur within the charnockite bodies. Finely foliated amphibolites inclusions are common in the charnockite occurrences at Awo.The Ore outcrop belongs to migmatitic gneiss group [21]. The generalized geologic map of south western Nigeria is shown in Fig. 1.




Scale 1:4,402,912.

**Fig. 1. Generalized Geological Map of South West Nigeria. (Source Geological Survey of Nigeria).**

## 3. Materials and Methods

Analysis of structural investigations were undertaken to select more desirable site for possible quarry development for dimension stones production. Hand mapping was used throughout this study. The joint orientations, joint persistence, aperture and joint spacing were measured.

The orientations of each joint set were determined by compass clinometers. The terminations of the joints were noted [13], while a description of the spatial fracture pattern mainly including the orientation of rock discontinuities, spacing relationships between single fractures and their lateral extent were carried out. Quantification of fracture patterns in some granite outcrops in the study area were examined for the purpose of describing block size distribution characteristics. For the analysis of the fracture patterns, AUTOCAD 3D$^{TM}$ method was used to generate in-situ block size distribution models of the granite outcrops.

AutoCAD™ creates 3D models for engineering drawings that can be adapted for geotechnical fracture model. In the AutoCAD model used for this study, the geotechnical data required for fracture model include the following:

- Relative position of the outcrop on the surface of the earth.
- spacing of the joints
- persistence of the fracture
- orientation of the joint sets

The stages involved in creating this model can be described as follows:

- pole plot of the fracture data to classify the fractures into sets
- determination of Fisher k factor in order to know how parallel the joints in a given set are. The higher the k factor, the more parallel the fractures in a given set;
- generate a rectangle with the same surface area as the outcrop under consideration using Auto CAD ™ and plot the strike of each of the fracture as they occurred along the scanline using the relationship between the dip direction and strike;
- individual blocks generated by the intercept of the joints are banded together and extruded to the required height based on the distance between sub-vertical features.

From the model created, the surface area and the volume of each block is estimated to give the distribution of the blocks within the required outcrop.

## 4. Results and Discussion

### 4.1. Joint orientation

Orientations were measured in terms of dips and dip directions of the fracture. In this study, most of the mapped joints have an orientation that fall within 84°/020° and 86°/300° sets as shown in Table 1. These patterns are compatible with the regional fracturing, which are predominantly NW-SE, NE-SW, NNE-SSW, ENE-WSW and WNW-ESE [21, 22].

Some secondary fractures were observed in Ore, Ikole and Awo granites. These fractures were attributed to the previous blasting activities at the sites. In Ewu, Ikere and Supare granites, this type of fracture were not visible since the outcrops are virgin and no previous blasting had taken place. Two sub-vertical joints are the dominant ones in the study area, while sub- horizontal features are observed in Ore, Ikole and Awo but with limited occurrence.

**Table 1. Joint Orientation Summary for Granite under Study.**

| Joint sets | Granite location | | | | | |
|---|---|---|---|---|---|---|
| **Orientation** | **Ewu** | **Ore** | **Awo** | **Ikere** | **Supare** | **Ikole** |
| **S1** | | | | | | |
| **Dip** | 85° | 85° | 87° | 84° | 86° | 86° |
| **Dip direction** | 344° | 317° | 299° | 318° | 307° | 321° |
| **S2** | | | | | | |
| **Dip** | 85° | 84° | 87° | 84° | 86° | 82° |
| **Dip direction** | 041° | 056° | 037° | 025° | 038° | 041° |

## 4.2. Joint persistence

The persistence of joints is characterized by their termination in accordance with the procedure suggested by an earlier worker [13]. In this study, the XX type joint persistence is dominant and RR type is in minority (Table 2). As a result of this, the termination index in this area is expected to be low. The joints that exhibit RR type were not observed in virgin outcrops such as Ewu, Supare and Ikere granites. Rather, it was observed in Ikole, Ore and Awo granites which further suggested that they originated from blasting effects. The DD type of persistence was observed in Awo, Ore and Ikole granites to be as a result of interception of horizontal jointing and two sub-vertical joints. The spacing of horizontal features was observed to be greater than 2m in the entire area. This is of great advantage for dimension stone production [9].

**Table 2. Joints Characteristics for Granite under Study.**

| Joint attribute | Granite location | | | | | |
|---|---|---|---|---|---|---|
| | Ewu | Ore | Awo | Ikere | Supare | Ikole |
| **Termination** | | | | | | |
| **DD (%)** | - | 10 | 10 | - | - | 10 |
| **DX (%)** | - | - | - | - | - | - |
| **RR (%)** | - | 5 | 5 | - | - | 5 |
| **RX (%)** | - | - | - | - | - | - |
| **XX (%)** | 100 | 85 | 85 | 100 | 100 | 85 |
| **Aperture** | | | | | | |
| **Indeterminate (%)** | - | - | - | - | - | - |
| **Open (%)** | 100 | 90 | 90 | 100 | 100 | 90 |
| **Close (%)** | - | 10 | 10 | - | - | 10 |
| **Infilling** | | | | | | |
| **Clay (%)** | - | - | - | - | - | - |
| **Mica (%)** | 90 | 90 | 90 | 90 | 90 | 90 |
| **Quart (%)** | 10 | 10 | 10 | 10 | 10 | 10 |

## 4.3. Aperture

Aperture measurements in the granites of the study area was observed to be relatively easy compared to those carried out in other parts of the world because the majority of the granite outcrops are without overburden. Closed joints observed in Awo, Ore and Ikole granites were found to occur due to blasting effect. Open joints, which are believed to be consequences of superficial displacement of the blocks, are about 1-2 mm wide. The open joint is about 90% in Awo, Ore and Ikole granites while it is almost 100% in virgin outcrop studied. Majority of the joints were filled with quartz and pegmatite. Closed joints, as observed in Awo, Ore and Ikole granites were short while open joints were longer.

## 4.4. Joint spacing

It was observed that largest percentage of spacing values for Ewu, Ikere, Supare, Awo and Ore granites are greater than 1.5 m. This spacing would provide in-situ block size distribution that can give commercial blocks [9]. The Ikole granite has largest distribution within 0.5 m and 2.0 m as shown in Fig. 2. This granite outcrop falls at the boundary between ‘exploitable’ and ‘unexploitable’.

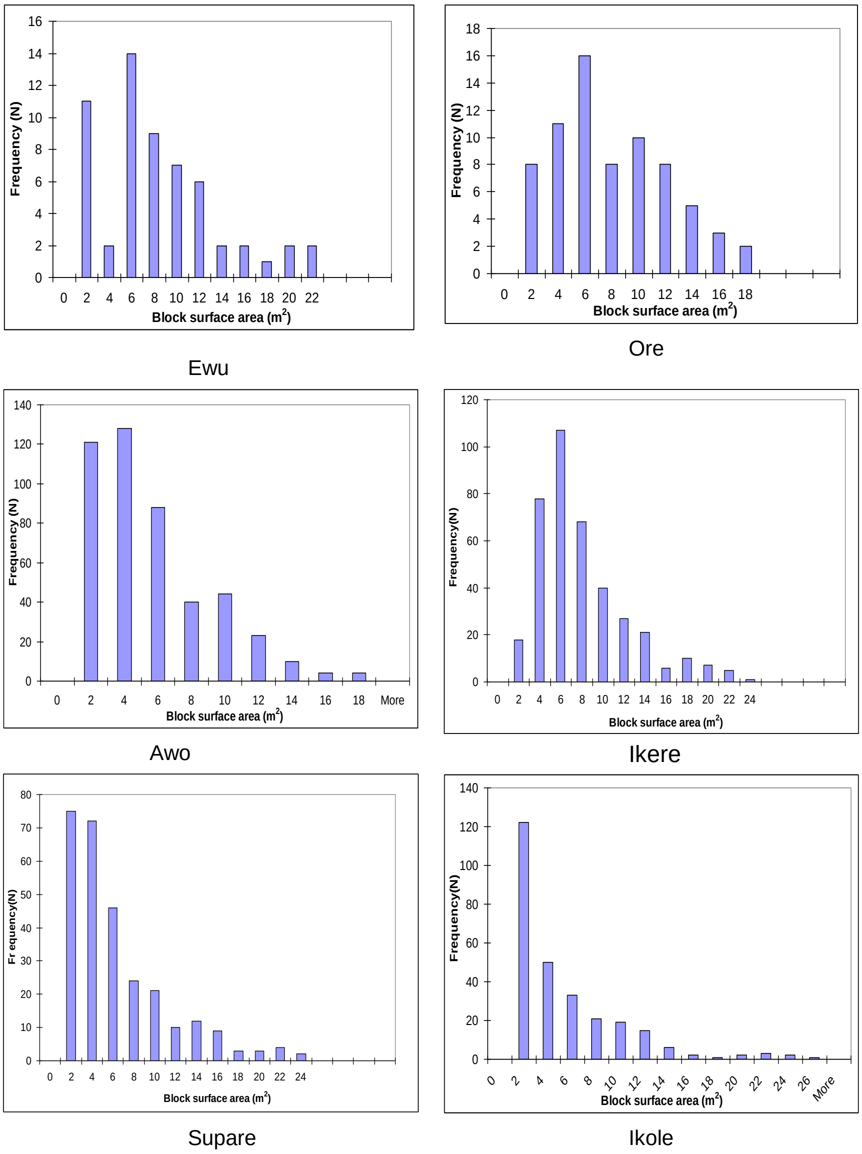



**Fig. 2. Block Size Distribution of Selected Granites in the Study Area.**

## 4.5. Empirical block size estimation

The general joint pattern shows that two main sub-vertical joints ($J_1$ and $J_2$) were dominant in all the selected granites. The sub-horizontal feature ($J_3$) varies in spacing from site to site, and 1.5 m spacing (which is the minimum spacing observed from all the sites visited) was used as spacing value for $J_3$ in the empirical block size estimation. The block sizes were estimated using joint spacing, block volume and modified volumetric joint count methods. It was observed from empirical block size estimation that Ikere, Supare, Ewu and Ore granites had bigger average block size when compared to Awo and Ikole granites. This can be attributed to the difference in their fracture patterns. Ikere, Supare, Ewu and Ore granites were observed to have wider spacing of sub-vertical fracture compared to Awo and Ikole granites.

## 4.6. Modified volumetric joint count

The issue of interest here is the relationship between the modified volumetric joint counts and the average in-situ block sizes. It can be observed that in Ikere, Supare, Ewu and Ore granites that had larger average block sizes had low modified volumetric joint counts while the Awo and Ikole granites that had small average block sizes had high modified volumetric joint counts, in agreement with earlier studies [9].

Based on the three methods used in this work for empirical block size estimation, it can be observed that the average block sizes obtained using joint spacing method is always higher than the value obtained when using block volume and volumetric joint counts, in agreement with an earlier study [6] which stated that the average block size obtained from joint spacing method must be used with care as it often exaggerates the block size. This exaggeration is significantly observed in all the studied granites in southwestern Nigeria as shown in Table 3. It is then therefore suggested that care must be taken when using the joint spacing method for block size estimation in detailed studies.

A modified volumetric joint count was calculated for the sites under consideration and relationship between the modified volumetric joint count and percentage of block surface area greater than 2 $m^2$ was established and the results are shown in Table 3 and Fig. 6. This result agreed with an earlier work [15], establishing a clear relationship between the volumetric joint count and in-situ block size, i.e., the lower the volumetric joint count, the higher the Geological Strength Index (GSI) as shown in Tables 4A-4F, and thus the higher the percentage of commercial blocks that may be produced.

Fracture network characterization as carried out revealed that for any granite outcrop to be economically suitable for dimension stone exploitation, the minimum percentage of block surface area greater than 2 $m^2$ is 30%. Based on this, 30% of Block Surface Area greater than 2 $m^2$ from Fig. 6 gives a corresponding modified volumetric joint count of 1.7 $m^{-1}$. The modified volumetric joint count (*Jv*) should not be above 1.7 $m^{-1}$ and must be at least 'Good' rock according to rock mass classification. The results showed that Ore, Ikere, Supare Awo, and Ewu had *Jv* below 1.7 $m^{-1}$ and are considered commercially exploitable as dimension stone. Ikole falls in the boundary zone. This indicated that care must be taken in exploiting these granites for commercial blocks as any variation in block size will render the outcrops uneconomical for commercial block production.

**Table 3. The Expected Recovery and Modified Volumetric Joint Count of Selected Granites in South Western Nigeria.**

| Granite locations | % > 2 $m^2$ | Expected recovery (%) | Expected waste (%) | Modified Volumetric joint count (*Jv*) ($m^{-1}$) |
|---|---|---|---|---|
| **Ewu** | 90 | 90 | 10 | 0.79 |
| **Ore** | 92 | 92 | 8 | 0.67 |
| **Awo** | 70 | 70 | 30 | 0.96 |
| **Ikere** | 96 | 96 | 4 | 0.80 |
| **Supare** | 75 | 75 | 25 | 0.79 |
| **Ikole** | 56 | 56 | 44 | 1.24 |

**Table 4A. Classification of Ikere Granite Outcrop Using Q-System, RMR and GSI System.**

| Q-Variable | Rating | $RMR_{89}$ Variable | Rating | GSI Variable | Value |
|---|---|---|---|---|---|
| RQD | 100 | UCS | 11 | Avg. spacing of set 1 | 3.26 m |
| $J_n$ | 6 | RQD | 20 | Avg. spacing of set 2 | 2.00 m |
| $J_r$ | 2 | Joint spacing | 20 | *Jv* | 0.81 $m^{-1}$ |
| $J_a$ | 0.75 | Joint Condition | 17 | Structural rating | 90 |
| | | Ground Water | 15 | Surface condition rating | 17 |
| TOTAL | 45 | | 83 | | 78 |
| Q - value= $RQD/J_n \times J_r/J_a$ = 100/6 × 2/0.75 | | | | | |

**Table 4B. Classification of Supare Granite Outcrop Using Q-System, RMR and GSI System.**

| Q-Variable | Rating | $RMR_{89}$ Variable | Rating | GSI Variable | Value |
|---|---|---|---|---|---|
| RQD | 100 | UCS | 12 | Avg. spacing of set 1 | 2.70 m |
| $J_n$ | 9 | RQD | 20 | Avg. spacing of set 2 | 2.38 m |
| $J_r$ | 2 | Joint spacing | 15 | *Jv* | 0.79 $m^{-1}$ |
| $J_a$ | 0.75 | Joint Condition | 17 | Structural rating | 90 |
| | | Ground Water | 15 | Surface condition rating | 17 |
| TOTAL | 30 | | 79 | | 75 |
| Q - value= $RQD/J_n \times J_r/J_a$ = 100/9 × 2/0.75 | | | | | |

**Table 4C. Classification of Awo Granite Deposit Using Q-System, RMR and GSI System.**

| Q-Variable | Rating | $RMR_{89}$ Variable | Rating | GSI Variable | Value |
|---|---|---|---|---|---|
| RQD | 100 | UCS | 13 | Avg. spacing of set 1 | 2.31 m |
| $J_n$ | 6 | RQD | 20 | Avg. spacing of set 2 | 1.90 m |
| $J_r$ | 2 | Joint spacing | 16 | *Jv* | 0.96 $m^{-1}$ |
| $J_a$ | 0.75 | Joint Condition | 17 | Structural rating | 85 |
| | | Ground Water | 15 | Surface condition rating | 17 |
| TOTAL | 45 | | 81 | | 75 |
| Q - value= $RQD/J_n \times J_r/J_a$ = 100/6 × 2/0.75 | | | | | |

**Table 4D. Classification of Ewu Granite Outcrop Using Q-System, RMR and GSI System.**

| Q-Variable | Rating | $RMR_{89}$ Variable | Rating | GSI Variable | Value |
|---|---|---|---|---|---|
| RQD | 100 | UCS | 13 | Avg. spacing of set 1 | 3.14 m |
| $J_n$ | 9 | RQD | 20 | Avg. spacing of set 2 | 2.13 m |
| $J_r$ | 2 | Joint spacing | 20 | $J_v$ | 0.79 $m^{-1}$ |
| $J_a$ | 0.75 | Joint Condition | 17 | Structural rating | 88 |
| | | Ground Water | 15 | Surface condition rating | 17 |
| TOTAL | 30 | | 85 | | 80 |
| Q - value= $RQD/J_n \times J_r/J_a$ = 100/9 × 2/0.75 | | | | | |

**Table 4E. Classification of Ore Granite Outcrop Using Q-System, RMR and GSI System.**

| Q-Variable | Rating | $RMR_{89}$ Variable | Rating | GSI Variable | Value |
|---|---|---|---|---|---|
| RQD | 100 | UCS | 12 | Avg. spacing of set 1 | 2.80 m |
| $J_n$ | 6 | RQD | 20 | Avg. spacing of set 2 | 3.21 m |
| $J_r$ | 2 | Joint spacing | 20 | $J_v$ | 0.67 $m^{-1}$ |
| $J_a$ | 0.75 | Joint Condition | 17 | Structural rating | 90 |
| | | Ground Water | 15 | Surface condition rating | 17 |
| TOTAL | 45 | | 84 | | 80 |
| Q - value= RQD/$J_n$ × $J_r$/$J_a$ = 100/6 × 2/0.75 | | | | | |

**Table 4F. Classification of Ikole Granite Outcrop Using Q-System, RMR and GSI System.**

| Q-Variable | Rating | $RMR_{89}$ Variable | Rating | GSI Variable | Value |
|---|---|---|---|---|---|
| RQD | 100 | UCS | 13 | Avg. spacing of set 1 | 1.20 m |
| $J_n$ | 6 | RQD | 20 | Avg. spacing of set 2 | 2.00 m |
| $J_r$ | 2 | Joint spacing | 15 | $J_{v\|}$ | 1.24 $m^{-1}$ |
| $J_a$ | 0.75 | Joint Condition | 17 | Structural rating | 85 |
| | | Ground Water | 15 | Surface condition rating | 17 |
| TOTAL | 45 | | 80 | | 75 |
| Q - value= RQD/$J_n$ × $J_r$/$J_a$ = 100/6 × 2/0.75 | | | | | |

## 4.7. Modified volumetric joint count

The overall results of the numerical modeling of block size distributions of selected granite in the study area Nigeria using AutoCAD™ 3D modeling are shown in Figs. 3 and 4. The analyses of the results obtained from these models were based on the minimum acceptable surface area of 2 $m^2$ of block for a commercial block as proposed by a worker [10]. The results of the analyses showing the in-situ block size distribution are provided in Figs. 2-6. Modified volumetric joint counts were used since the modeling was based on the surface area created only by sub-vertical joints.

From the results of AutoCAD™ 3D modeling of the selected granites as shown in Figs. 3 and 4, it can be observed that in Ikere, Awo, Ore and Ikole granites, two regular sub-vertical fractures existed throughout the outcrop while random jointing was observed in Supare and Ewu granites in addition to the two sub-vertical joints. It was observed that despite the relatively similar spacing as between Supare and Ewu granites on one hand, and Ikere and Ore granites on the other hand, the former group has recovery (i.e. percentage of block with surface area > 2 $m^2$) lower than that of the latter group.

Awo and Ikole granites were observed to have lower expected recovery (i.e., percentage of block with surface area > 2 $m^2$) when compared to Supare, Ore and Ewu granites from the model results summarized in Table 3 and Figs. 3-5. This can be attributed to the differences in their joint spacing. It was also observed that sub-vertical joint in Supare, Ikere and Ewu granites are more widely spaced than that of Ikole and Awo granites which explained the difference in their expected recoveries (i.e. percentage of bock with surface area > 2 $m^2$).

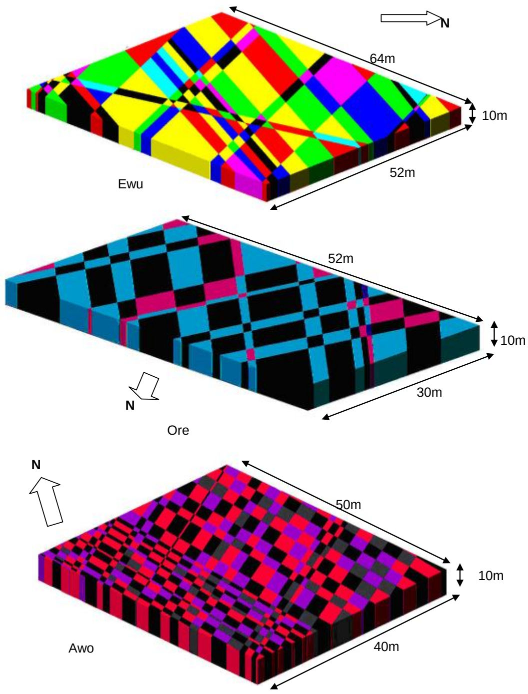



**Fig. 3. AutoCAD™ Models of Fracture Patterns in Ewu, Ore and Awo Granites.**

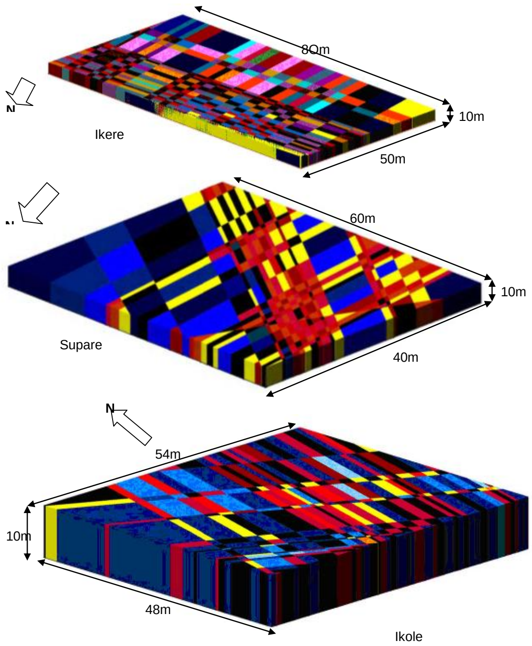



**Fig. 4. AutoCAD™ Models of Fracture Patterns in Ikere, Supare and Ikole GRgranites.**

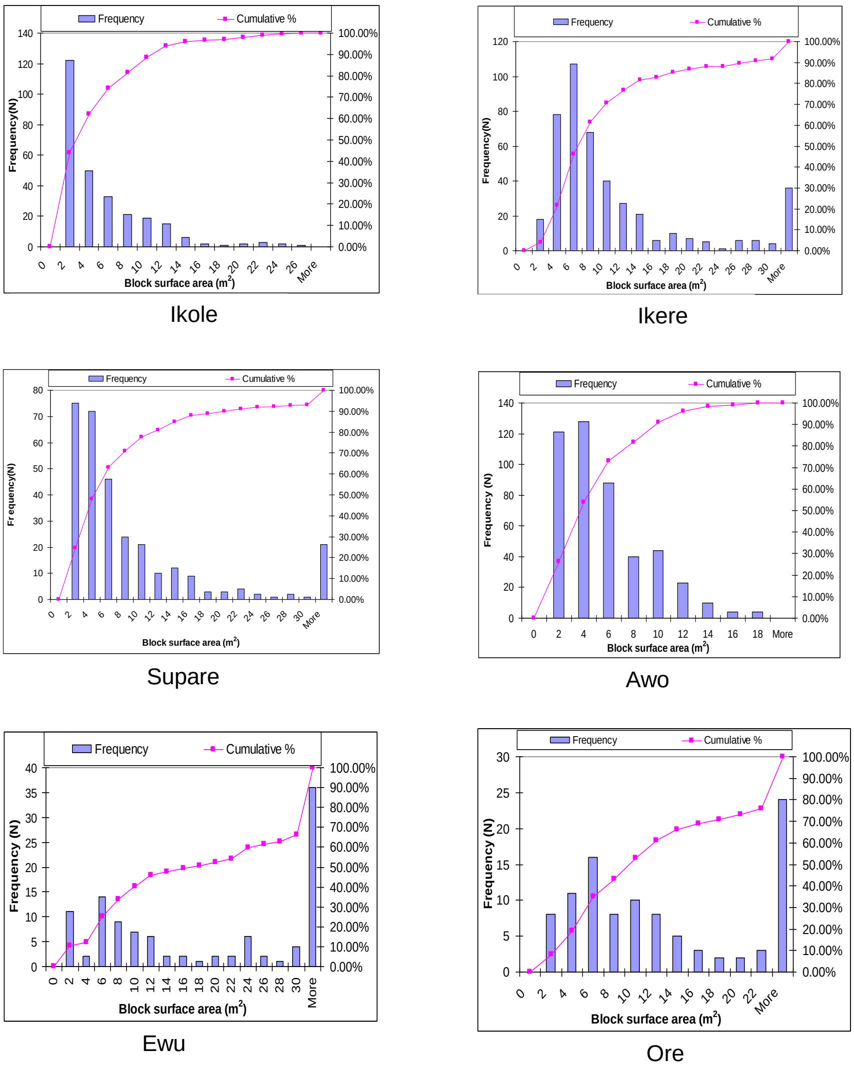



**Fig. 5. Combined Frequency and Cumulative Frequency Distribution (%) of Block Sizes.**

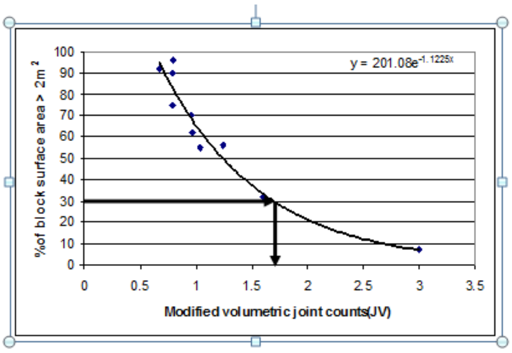



**Fig. 6. Relationship between Modified Volumetric Joint Counts and % of Block Surface Area > 2 m$^2$.**

## 5. Conclusion

A new approach to in-situ block size estimation using AutoCAD™ was introduced on assumption of continuous joint distribution. The result of the modeling provides basis for classification of granites outcrop for commercial exploitation.

Outcrops with higher modified volumetric joint counts were noticed to have low potential recovery. Ewu, Awo, Ore, Ikere, and Supare outcrops have low Modified volumetric Joint count ($J_v$) which indicated that they can be economically exploited for dimension stone production. Ikole has Modified volumetric Joint count of 1.24 $m^{-1}$ which is closer to the maximum expected recovery value (1.7 $m^{-1}$) for economical exploitation of the granite outcrops. These indicated that care must be taken in exploiting the Ikole outcrops for dimension stone production because any error may render the outcrops unexploitable for dimension stones.

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