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Evaluation of Suitability of Rocks Using Volumetric Joint Count for Dimension Stone Quarry in Supare, Ondo State, Southwestern Nigeria

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Abstract
Fracture characterization of rocks in Supare, Ondo State, South western, Nigeria was examined in respect to their suitability for dimension stones. Detailed geological mapping of the area carried out on scale of 1:12,500 indicated that the dominant rocks are granite-gneiss followed by granite and migmatite. The principal joint direction trends NNE-SSW which also corresponds to the regional structural pattern of the area. The volumetric joint count for discontinuities was carried out via Scan Line mapping and values obtained from all examined outcrops ranges from 0.1 to 5.33m^{-3} with average spacing varies from 0.7 to 2.45m. The volumetric joint count revealed that most of outcrops have volumetric joint value less than 3.0 and can be exploited economically for dimension stone production with potential of producing medium block. A few of the granite gneiss recorded volumetric joint count less than 1.0 and have the potential of producing large block while a few of the granite outcrops have higher volumetric joint count greater than 3.0 and thus can be quarried as aggregates for construction use in building and road construction. It is suggested that the geologist and the mining engineers should take into cognizance the geological evaluation (joint density) as fundamental in prospecting and exploration for dimension stone quarry.

Keywords: Supare Southwestern Nigeria, Dimension Stone, Volumetric joint count.

Introduction
The term 'dimension stone' covers a wide variety of naturally occurring stone used for the external and internal decoration of buildings. They include limestone, marble, sandstone, gabbro, granite, serpentine, and gneiss (Smith, 1999). According to Dunda 2003, for a rock body to qualify as a deposit of dimension stone, the following criteria must be considered:
(i) Geological criteria (frequency and location of discontinuities, fracture/ joint density). (ii) Technical criteria (Physical and Mechanical properties of the rock).
(iii) Decorative criteria (colour, texture, mineralogy).
(iv)Technological criteria (workability of the rock mass processing which include cutting, polishing, grinding and carving.
Geological and geotechnical characterization of dimension stone are essential for construction industry and will help in selecting appropriate use of these building stone. The views of mining and civil engineers as well geologists on prospecting for suitable rocks for dimension stones have been studied. Saliu *et al.*, 2012 showed the current technology and mechanization employed in blocking, that is exploiting and processing Nigerian granite measured up to the standard of the world most advanced countries. They inferred that granites processing industrially demands large block dimension, and the large block size production is being controlled and regulated by the natural fracture pattern of the outcrops intended to be used. Harrison and Hudson (2000) concluded that the characteristic of individual joints such as trace length, orientation, aperture, planarity, roughness, location are used in classification and grouping of joint and surface morphology. They revealed that, the most significant parameters for evaluating the geo-mechanical properties of rock mass are the joint trace length. Fracture network characterization, persistence of fractures and density are imperative in determining the in-situ block

size distribution of granitic outcrops, using either numerical or empirical methods (Sousa, 2007). The volumetric joint density (J_v), joints spacing (S_n) and block volume methods are typical examples of empirical methods. Volumetric joint density is a parameter recommended for evaluating and assessing block sizes (International Society of Rock Mechanics, 1981).It is a measure of joints intersecting a volume of rock mass. It is defined as number of joints per m^3. Loudes *et al.*, 2000 recommended (2.4m x 1.3m x 0.7m) at least as for a block size. 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 $2m^2$. Priest and Hudson (1981) studied the probable means used for fracture measurement which include drill hole method, geophysical acoustic method, and surface exposure method which include both hand mapping and more recent application of remote methods such as photogrammetry.

An integration of both scan line and window mapping are appropriate for dimension stone prospection, evaluation and exploitation where detailed fracture characterization is a requirement for in-situ block size assessment (Palmstrom, 2005). Joint set spacing is the distance between individual joint within a joint set. The joint spacing and average joint spacing are frequently used in the assessments, evaluation and description of rock masses.

The volumetric joint density (J_v) as termed by Palmstrom (1986) and Sen and Eissa (1991) can be analysed from the joint set spacing within a volume of rock mass as given in equation(l):

$$Jv = \frac{}{S_1} + \frac{}{S_2} + \frac{}{S_3} + - - - - \quad ...(1)$$

where S_1, $S_2$and S_3 are joint set spacing.

In addition, random joint can be included by assuming a random spacing (Sr) for each of these. According to Palmstrom (1985), experience has indicated that this can be set to Sr = 5m; thus, the volumetric joint count can be expressed generally as

$$Jv = \frac{1}{S_1} + \frac{1}{S_2} + \frac{1}{S_3} + - - - - + \frac{N_r}{5} \quad ...(2)$$

In this case Nr = number of random joints. Mathematically, Jv can be easily measure from common joint observations, since it is a function of measurements of joints set spacing or frequencies. In an event where many irregular or random joint occur, Jv can be calculated by counting all joints observed in an area of known size.

Physiography of the Study Area

The study territory has a low and high relief with elevations ranges between 300m – 500m. In the south western part is a river that is ephemeral as it flows during the raining season and dries up during the dry season. There are two major rivers in this location namely River Omi-oruwe and River Akure, both characterized with different distributaries.

Land Use

The Low-lying terrains of the study area are cultivated for farming yam, corn and cocoa in a very large scale. A mechanized active dimension stone quarry (Sutol Crushed Rock quarry, Supare) is situated to south west central area along Supare- Emure road to the west. Supare covers hectares of land that is divided into different land use categories like government, educational, industrial and institution. Supare central part is densely populated with its inhabitant engaging in subsistence farming and petty trade.

Geology and location of the Study Area

The study area lies between latitude 7°27' – 7°29' N and longitude 5°40' – 5°42' Eon Owo sheet 265 NW. The area was mapped on a scale of 1:12500. It covers an estimate of area of about $13.4km^2$. Supare Akoko lies within the undifferentiated migmatite-gneiss complex of Nigeria Basement rock as classified by Rahaman (1973) and these accounts for over 99% of the basement rock in the terrain. The area is accessible through good road network that passes through the area in the east-west direction running from Akungba Akoko (in the east) and Emure (in the west). This area is dominated by three rock type: granite-gneiss, granite and migmatite. The geological map is shown on figure 1.

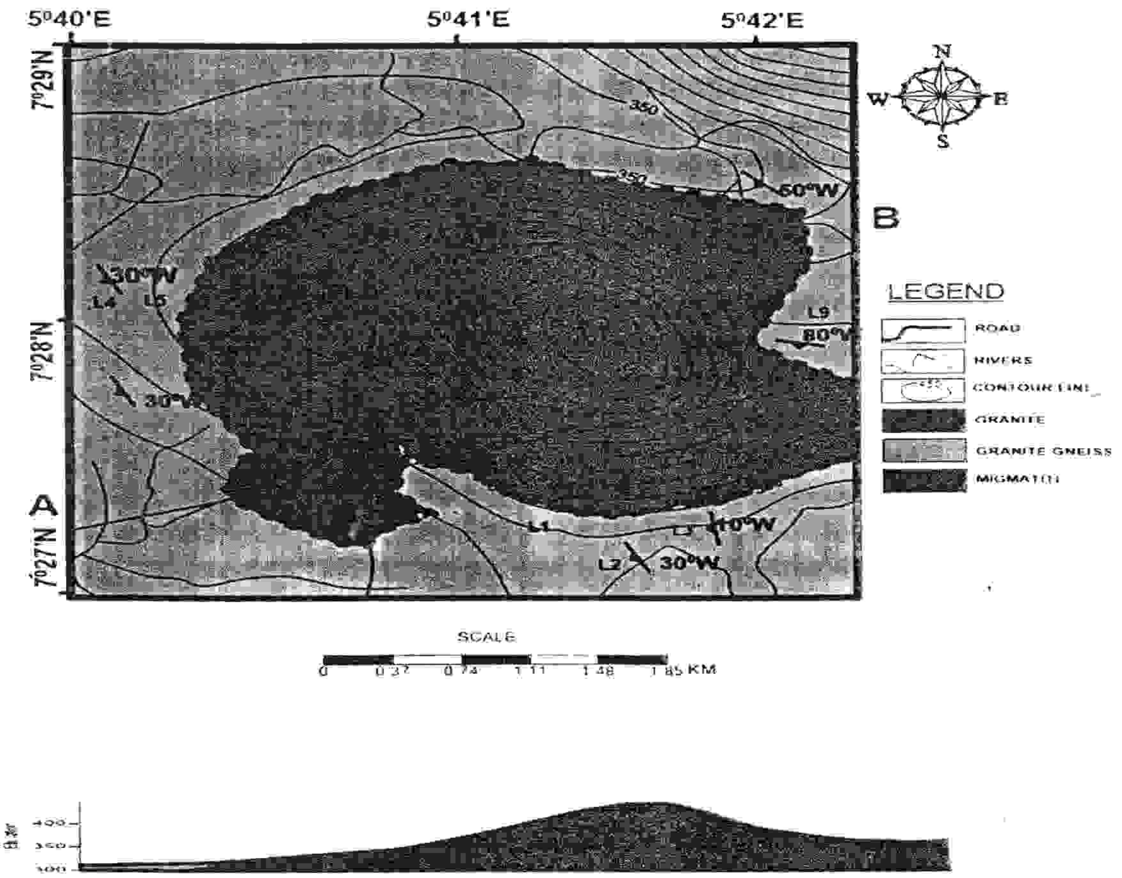

Figure 1: Geological map of the area of study

Materials and Methods

Structural analysis investigation was carried out to select more desirable outcrops for dimension stone quarry development. Orientations of the joint set were determined using compass clinometer. Quantifications of fracture pattern of rocks were examined to describe the block size distribution characteristics. Rock samples were obtained from the field with the use of geological hammer. The coordinate of the sample location was obtained using global positioning system (GPS) and measuring tape. Scan line mapping was carried out by the use of measuring tape between 20-30 metres length, tensioned at two places and laid on the rock face. Among the features for each discontinuity documented are:

(i) The scan line distance to the point at which the fracture intersects the scan line
(ii) Strike and dip direction
(iii) Trace length of the fracture
(iv) Number of the end point of the fracture observed on the face.

Result and Discussion

Field Observation

In Supare persistence joint is dominant and 60% for joint spacing are more than 1.5 meters. This spacing would produce in-situ block size distribution that can yield block commercially (Sousa, 2007). The joints, elevation and GPS readings are presented on table 1while table 2A is a General Discontinuities Properties of the Selected Rocks. Tables 2B and 2C contain the Mean Joint Spacing(S)m of Rocks and Joint Orientation Summary of Rocks (000/00)^0 respectively.

Table 1: Summary of Elevation and GPS Reading of Sample Points

S/No	Location (L)	Rock Type	Longitude (E)	Latitude (N)	Elevation (m)
1.	L1	Granite gneiss	005°41'16.8"	07°27'14.4"	355
2.	L2	Granite gneiss	005°41'34.8"	07°27'03.6"	362
3.	L3	Granite gneiss	005°41'42.0"	07°27'14.4"	388
4.	L4	Granite gneiss	005°40'04.8"	07°28'01.4"	369
5.	L5	Granite	005°40'15.6"	07°28'01.2"	388
6.	L6	Granite gneiss	005°41'45.6"	07°27'25.2"	382
7.	L7	Migmatite	005°40'48.0"	07°27'32.4"	348
8.	L8	Granite	005°42'03.6"	07°28'15.4"	348
9.	L9	Granite gneiss	005°42'10.8"	07°28'04.8"	349

Table 2A: General Discontinuities Properties of the Selected Rocks

S/No	Sample Location	Scan Line Length (m)	Volumetric Joint count (joint/m3)
1	L1	21	1.85
2	L2	20	1.3
3	L3	20	3.92
4	L4	25	0.1
5	L5	20	2.39
6	L6	20	5.33
7	L7	20	2.45
8	L8	20	4.3
9	L9	21	2.45

Table 2B: Mean Joint Spacing(S)m of Rocks Under Study

Location	L1	L2	L3	L4	L5	L6	L7	L8	L9
	2.7	1.97	1.0	11.0	0.97	1.2	1.7	1.15	1.80
	1.60	3.70	1.24	-	2.10	0.73	1.64	1.23	1.34
	2.83	1.57	0.83	-	2.15	0.75	1.84	1.04	1.57
	2.0	-	1.10	-	2.45	0.84	1.67	1.67	2.0

Table 2C: Joint Orientation Summary of Rocks Under study (000/00)^0

Location	L1	L2	L3	L4	L5	L6	L7	L8	L9
Strike	010	172	185	290	050	190	058	081	010
Dip	40	60	18	36	44	10	47	40	80
Strike	070	170	188	-	058	030	240	010	070
Dip	40	76	38	-	40	50	10	18	70
Strike	050	268	190	-	250	350	030	062	080
Dip	30	80	70	-	53	28	10	65	36

Structural geology

The observed structural features such as joints, faults and foliation were measured using compass clinometer and the data obtained were used to plot a rosette diagram for the area using rock-works software (2006 version) as shown in figure 2. The rossette diagram revealed the structural configuration of the study area which is useful in mineral prospection, exploration and exploitation. It also indicates the zone of weakness for the rocks intended for use as dimension stones. The principal joint direction in the area is NNE-SSW (Fig. 2), which conforms to the dominant structural deformation of the outcrops in the study area due to tectonic movement. From the rosette diagram (Fig 2), the highest fracturing was along NNE-SSW which also corresponds to the regional structural pattern of the area. It implies that the orogenic and epirogenic forces acted on the rock in the area along NNE-SSW axis.

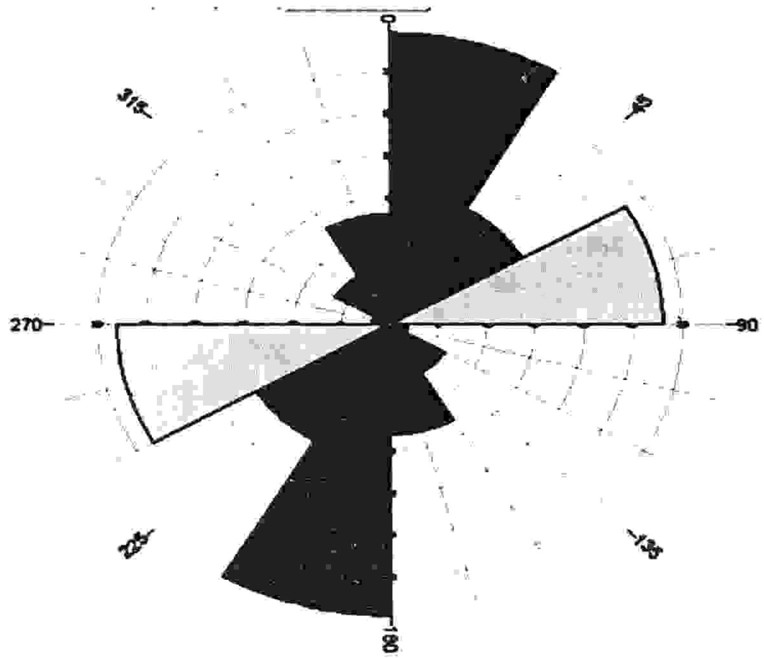

Figure 2: Rosette diagram of the Study Area

Volumetric Joint Density/ Count

The Volumetric joint counts were acquired via fracture network characterization for the nine outcrops under consideration to identify suitable outcrops for dimension stone production. The results as shown in Table 2 show that locations L1, L2, L4, L7 and L9 have a Jv, value less than 3.0. This agree with earlier works of Elci and Turk (2014) that any outcrop that would be economically exploited for dimension stone production must have a Jv, value less than 3.0. Location L3 falls in the boundary zone, which implies that caution should be taken in exploring this granite gneiss for commercial blocks as it could render the outcrop uneconomical for commercial block production. The values of Location 6 and 8 exceeded the recommended limit of 3.0 therefore cannot be considered for dimension stone production. The volumetric joint count (Jv), of L4 is less than 1.0, implying it has the potential of producing large block while other outcrops fall within the third category of description of blocks, which indicated that they have the potential of producing medium blocks as proposed by ISRM in (Sousa, 2010). The relationship between calculated volumetric joint counts and their respective outcrops are represented in Figure 3.

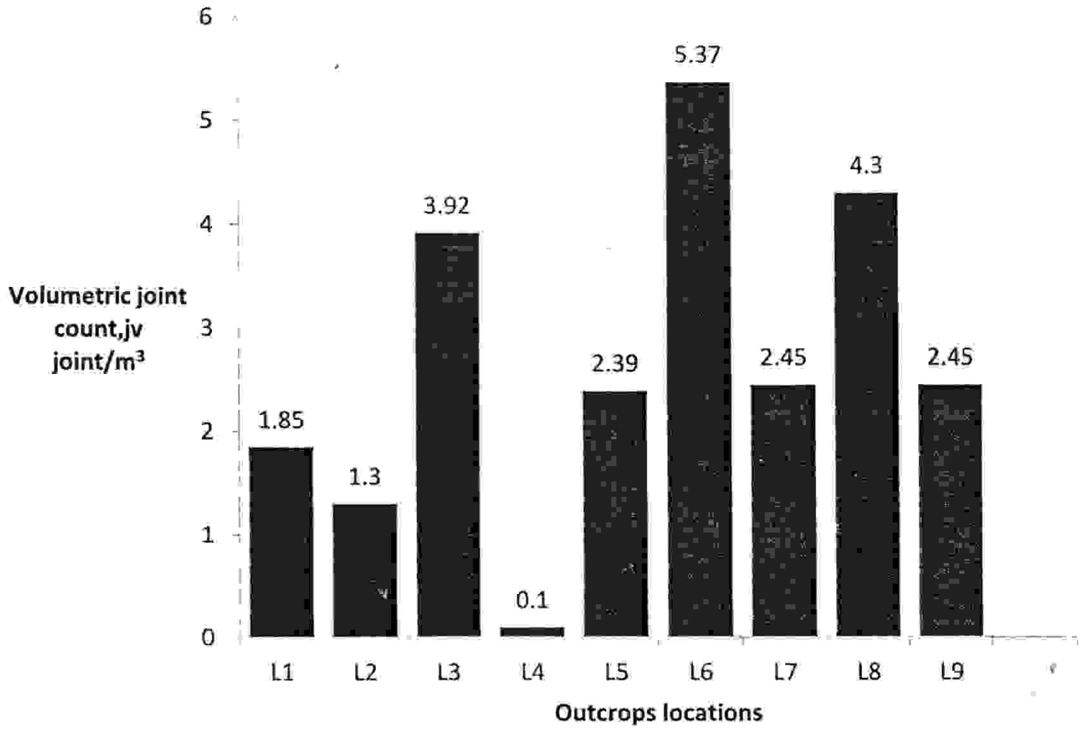

Figure 3: volumetric joint counts of selected outcrops

Conclusion and Recommendations

Conclusion

Geological parameters, mechanical and physical properties are the controlling factors in the classification of dimension stone. Geological mapping as well as various outcrops assessed indicates that the area explored is underlain by medium to coarse grained granite, granite-gneiss and migmatite with granite-gneiss dominating the study area. The results revealed that outcrops with higher volumetric joint count greater than 3.0 have low recovery potential. Location L1, L2, L4, L5 L7 as well as L9 have volumetric joint count values ranging from 0.1-2.45 m^{-3} which is closer to maximum recovery value of 3.0, thereby indicating that they can be economically exploited for dimension stone production and with the potential of producing medium blocks except for L4 outcrop with less than 1.0 Jv that has the potential of producing very large block. However, Location L3, L6 and L8 could be regarded as aggregates stone deposit and thus be quarried for constructional work and common use.

Recommendation

Mining, Building, Structural and Civil Engineers should not only dwell with geotechnical assessment of rocks as the only determinant in the selection and production of dimension stones but should take into cognizance the geological evaluation (joint density) as fundamental in prospecting for suitable outcrops for dimension stone quarry.

This is imperative because the economic feasibility of a quarry depends on the block size production of the quarry. However, it is needful that all stakeholders and stone merchant should know the importance and the unique properties of natural stone when selecting dimension stones as a component in a building system, hence involvement of professionals from prospecting stage to completion should be given priority so as to obliterate completely the shortcomings quacks.

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