Feasibility Study on the Suitability of Granite Outcrops for a Proposed Quarrying Operation at Kpoyipma Community, Kaduna, North-western Nigeria

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Abstract

This study carried out a feasibility study to determine the suitability of granite outcrops located at Kpoyipma community in Kagarko Local Government Area of Kaduna State, Nigeria, for a proposed quarrying operation. In the study, a geometric survey of the community was carried out to determine the lateral extents of the granite outcrops. Samples of granite collected from outcrops A and B were prepared and tested in the laboratory for the determination of their physical, mechanical and chemical properties that are required for determining the suitability of the granite rock for construction and engineering purposes. The results of the study showed that the values of all the parameters determined from the two outcrops (East and West) considered are within the specified ranges of the globally accepted standards. The results from the uniaxial compressive test with an average strength of 156.29 MPa indicated that the outcrops are very competent for aggregate production and can be used for any engineering purposes. The results of the point load test showed a tensile strength of 6.04 Mpa indicating that the outcrops are suitable and moderately brittle for massive quarrying operation. Petrographic/thin section results also indicated that outcrop A is a coarse grained granitic rock, while outcrop B is hornblende-biotite granite, thereby revealing their combined volumetric joint counts which make them potentially suitable for quarrying. The rocks are found to be hard granitic rock, suitable for use in monuments and ornaments when cut and polished as dimension stones and construction works. It was estimated that the granite deposit of 150,102,190 tonnes is large enough for the establishment of a quarry in the area. Hence, the proposed quarrying operation in the area is considered feasible and suitable.

Keywords: Chemical properties, Granite outcrops, Mechanical properties, Quarrying operation.

1 Introduction

The increasing demand for granite aggregates in developmental projects and decoration purposes has assumed an unprecedented dimension thereby creating a revolutionary trend in the mining and construction industries. Granite use has continued to spark up much more especially in the areas of infrastructural development and road construction across new capital cities in countries witnessing project execution and expansion. Although wastes generated from the use of granite aggregates alone such as granite dust have been estimated to generate hundreds of millions of tonnes (Garas *et al.*, 2014) and constituted serious environmental threat (Lokeshwari and Jagadish, 2016); incorporating granite fines in building block as a replacement to fine aggregates and using granite fines maximally in replacement of fine aggregates would save a large quantity of natural sand and reduce environmental pollution associated with granite fines.

Granite is massive, hard, and tough, lacking internal structure thereby making it widely suitable to be used as a construction stone (King, 2005). Its average density varies between 2.65 and 2.75 g/cm3 (165.4 - 171.7 lb/ft3). Its compressive strength usually lies above 200 MPa, and its viscosity near STP is 3 – 6 • 1019 (Panova *et al.,* 2014; Anon., 2015). The melting temperature of dry granite at ambient pressure is 1215–1260 °C (2219–2300 °F); it is strongly reduced in the presence of water, down to 650 °C at a few kBar pressure (Holland and Roger, 2001). Granite has poor primary permeability but strong secondary permeability. Figure 1 shows some granite composition ranges for igneous rocks.

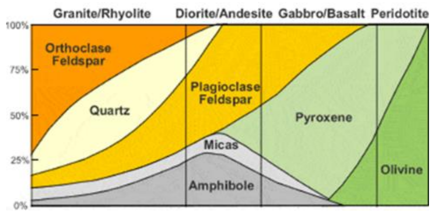

Fig. 1 Generalised Composition Ranges of Common Igneous Rocks (Source: King, 2005)

A quarry is an open excavation from which useful stone is extracted for building and engineering purposes (Adeyi *et al.*, 2019). It is concerned with the art, science, and technology of extracting valuable construction materials through systematic exploitation with the aid of drill holes, charged and blasted in benches for the benefit of man at profit. Granite quarries produce extracted granite rocks-that are transported to the crushing units for further particle size reduction before the aggregates are transferred to the screening machines for eventual sizing (Adeyi *et al.*, 2019). Crushed rock aggregates from granite quarrying are the materials used by the construction and building industries to fulfill their demands. Thus, the utility of the aggregates in engineering construction is a function of their physico-mechanical and petrographic characteristics (Agyeman *et al***.**, 2019; Naeem *et al*., 2014; Petrounias *et al*., 2018).

Investigation of the physical and mechanical properties of rocks is a significant parameter in the design of geotechnical structures. These rock properties are widely considered in engineering projects, and parts of what should be investigated include the parameters that affect the drilling condition of the rock. Adebayo and Adetula (2013) observed in their work that uniaxial compressive strength, texture and grain size, drilling rate index**,** and equivalent quartz content (EQC) significantly affect drilling conditions of the rocks. According to Takarli and Prince-Agbodjan (2008), rocks' physical and mechanical properties depend strongly on the void network. Such design should be planned according to the type of structures, loading characteristics, and rock bearing strata properties. The physical and mechanical impacts of granitic rocks, like other hard rocks, also have a significant influence on quarrying equipment in several ways, particularly considering the relationship between the physical and mechanical properties of rock and power consumption of such equipment (Korman *et al*., 2014). Parts of the investigation are the design aspects and possibilities for sharing failures which must be studied. Determining the effects of mineralogy and microstructure on the final strength of rock materials is also an important consideration (Petrounias *et al*., 2018). Hence, appropriate laboratory tests must be carried out to determine the rock properties before the final design stage. Given the imperative to accomplish these important technical requirements, this study is aimed at determining the suitability of granite outcrops situated at Kpoyipma community in Kagarko Local Government Area of Kaduna State, North-western Nigeria, for a proposed quarrying operation.

2 Materials and Methods

2.1 Location and Accessibility of the Study Area

The quarry site is about 3 km South East of the host community, Kpoyipma. This community is about 10 km North of Bwari town in the Federal Capital Territory (FCT), Abuja. The site is easily accessible by a major road that links Abuja to Kaduna by heading northward for about 9.8 km from Bwari to locate Lansata village in Kaduna State. Although little is known about Kpoyipma village, Lantata is about 2 km west of the community (see Fig. 2).

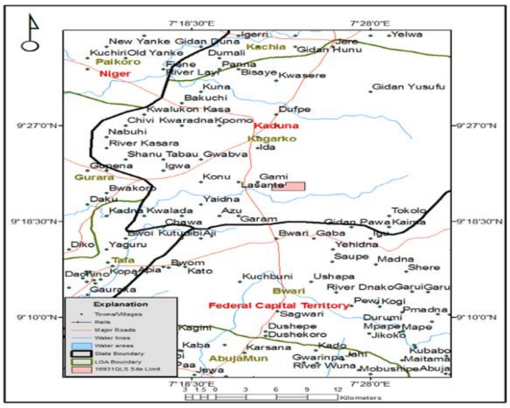

Fig. 2 Accessibility Map of the Study Area (Adapted from Anon., 2009)

The study area is defined by Longitude 07^0 22' 45" and 07^0 23' 30"- 070 24' 30", and latitude 090 21' 15" and 09^0 21' 45"- 09^0 22' 00", covering an area of about 3.6 sq. km which is 18 Cadastral Units (CUs). It falls within the Federal Survey of Nigeria Topographic Map Sheet 186NE (Abuja), 1:50,000 bounded in the North by Bishini, in the West by Paiko, in the South by Kuje, and Gitata in the East.

Table 1 below shows the polar coordinates of the granite outcrop areas, while Figure 3 shows the location map of the area.

Table 1 Site Coordinates of Outcrops (WGS 84 Coordinate System). LONG, LAT, STN represent Longitude, Latitude and Control station.

S/N	16931ML Site (GCS)		16931ML Site (UTM Zone 32)	
STN	LONG. X	LAT. Y	LONG. X	LAT. Y
CB1	07^{0} 22' 45"	09^{0} 21' 45"	322006	1035339
CB2	07^{0} 23' 30"	09^{0} 21' 45"	323379	1035333
CB3	07^{0} 23' 30"	09^{0} 22' 00"	323381	1035794
CB4	07^{0} 24' 30"	09^{0} 22' 00"	325212	1035785
CB5	07^{0} 24' 30"	09^{0} 21' 15"	325206	1034403
LB	07^{0} 22' 45"	09^{0} 21' 15"	322002	1034418

Fig. 3 Location Map of the Study Area (Adapted from Anon., 2009)

For site evaluation of outcrops A and B in the study area, the following factors were considered: substantial exposure, moderate positive relief, lithological uniformity, suitable joint density, orientation strength and durability, observation of deleterious minerals and proximity to infrastructure and demand. This is necessary to determine the prospect of the outcrops through depiction by the site location map, the relief map, vector map, and site observations. Figure 4 shows the regional geological map of parts of the study area.

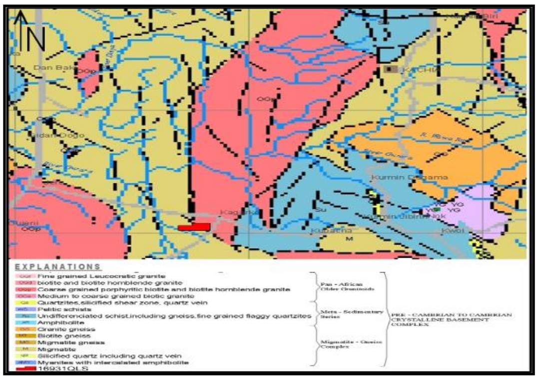

Fig. 4 Regional Geological Map of Part of the Area (Adapted from Anon., 2009)

Fig. 5 Exposure of the Granite Outcrop Showing its Relief

2.2 Data Collection and Laboratory Analysis

Samples of the granite rock were collected from the deposit located in the Kpoyipma community in Kagarko Local Government Area of Kaduna State, North-western Nigeria, with the use of sledge hammer and were carefully labeled. The collected samples were duplicated and sent to the laboratory for both geochemical and geotechnical tests.

Fig. 6 Measurement of Minor Joint direction during Mapping

The visual and aesthetic features of the granite outcrops were evaluated by their colour, texture, grain size, and flaws. In-situ determination of these properties was carried out on field and samples collected from the deposit were studied visually, and with the use of hand lens to ascertain their colour and textures respectively. The granite rock is light coloured and is composed of crystals of quartz, feldspar, and dark mafic mineral which include mica and hornblende. The predominant mineral in the granite rock is quartz. The texture of the rock from the two locations is fine grained. They have no flaws, no visible plane of weakness and are free of defects. Rock examination was conducted on samples of granite outcrops A and B to determine the mineralogical composition of the granitic rocks thereby providing information on the likely weathering characteristics and their amenability to polishing. The examination procedures of rock identification of colour, luster and shape of the outcrops adequately described the characteristics of the predominant mineral in the samples (Cull, 2009).

Fig. 7 Labeled Granite Samples from the Study Site

Test for physical and mechanical properties of the granite outcrops was carried out in accordance with American standard for Testing Materials (ASTM) D 2487 and International Society for Rock Mechanics (ISRM) to determine the quality of aggregate produced in terms of the strength when used for engineering purposes. Physical and mechanical tests were carried out from two standard certified laboratories which are:

i. Rock Mechanic Laboratory, Department of Mining Engineering of Federal University of Technology Akure; and

ii. Engineering Laboratory, Department of Civil Engineering, Kaduna Polytechnic, Kaduna.

Cylindrical core samples were prepared from the rock samples collected from the granite outcrops for the determination of the uniaxial compressive strength of the granite rocks of the two locations. All the rock samples were prepared and tested to the standard of the International Society for Rock Mechanics (ISRM). The tests were performed under free laboratory atmospheric conditions because the objective was to relate laboratory tests to field conditions. Irregular block samples were also prepared from the samples of the outcrops collected from the field. The samples were thereafter tested to determine the tensile strength of the rock using Point Load Tester. The determination of slake durability of the granite rock from the two outcrops was also carried out. In this study, hardness of the rock was determined with the use of mechanical tools. Samples of the granite rock collected from the field were prepared in the laboratory and tested to standard for hardness with the use of Schmidt Hammer Rebound Value. The laboratory procedures suggested by Adebayo et al., (2010) concerning uniaxial compressive strength (UCS), point load strength index (Is) and Schmidt Rebounds Hardness Value based on ISRM (Anon., 1981), ASTM (Anon., 2001) D 2938 and ASTM (2001) D 5731 and Jacobsson (2007) for intact rock uniaxial compression test were adopted in this study to ensure accuracy of results.

Perimeter survey of the outcrops was carried out using prismatic compass with tripod, ranging poles, global positioning system (GPS), 50 meter tapes, arrows and cutlasses. Figure 7 shows the perimeter survey of the outcrops. Reserve estimation of the granite outcrops (A and B) was also carried out using graphical (manual) method of geological units, computer modeling and polygonal assessment frameworks with the help of software system as shown in Fig. 8. The procedures for perimeter survey and reserve estimation of the granite outcrops were carried out in conformity with guidelines under the United Nations Framework Classification of Mineral Reserves/Resources (Anon., 2003).

3 Results and Discussions

3.1 Results of Perimeter Survey and Estimation of the Granite Outcrops

The estimation results for both outcrops A and B are shown in Tables 2a and 2b as well as Figures 8, 9, and 10. The results have shown that outcrop B is deeper with a total height of 2,886 m above the ground level as compared to that of outcrop A with a total height of 131 m. Thus, there is likelihood of more mineralisation within the outcrop B than outcrop A on account of higher thickness and more contents as indicated by Anon. (2003).

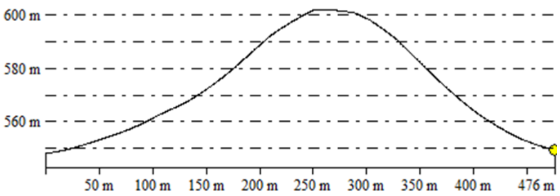

Fig. 8a: Granite Deposit 'A' Cross Section

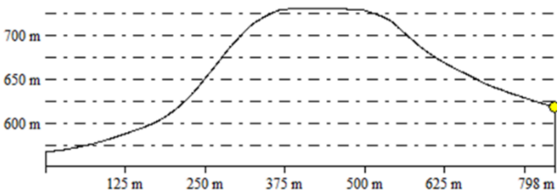

Fig. 8b: Granite Outcrop 'B' Cross Section

Fig. 9 Perimeter Survey of the Outcrops

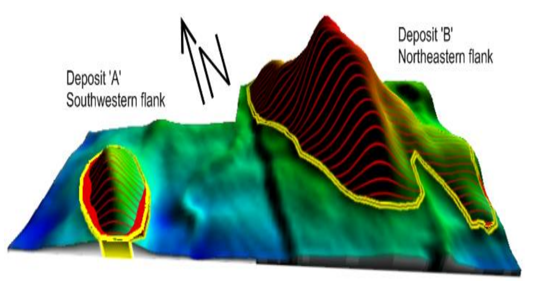

Fig. 10 3-D Model of Granite Outcrops 'A' and 'B' in the Study Area

Table 2a Estimation of Granite Outcrop A

Location	(A) Spot height (m)	(B) lowest ground level spot height (m)	(A) – (B) height above ground level (m)
1	600	556	**44**
2	590	556	**34**
3	588	556	**32**
4	573	556	**17**
5	560	556	**04**
Total height above ground level			**131**

Table 2b Estimation of Granite Outcrop B

Location	(A) Spot height (m)	(B) lowest ground level spot height (m)	(A) – (B) height above ground level (m)
1	732	556	**176**
2	730	556	**174**
3	728	556	**172**
4	710	556	**154**
5	708	556	**152**
6	700	556	**144**
7	690	556	**134**
8	686	556	**130**
9	680	556	**124**
10	670	556	**114**
11	666	556	**110**
12	662	556	**106**
13	660	556	**104**
14	654	556	**98**
15	650	556	**94**
16	646	556	**90**
17	642	556	**86**
18	640	556	**84**
19	636	556	**80**
20	628	556	**72**
21	616	556	**60**
22	612	556	**56**
23	608	556	**52**
24	606	556	**50**
25	604	556	**48**
26	600	556	**44**

27	598	556	**42**
28	596	556	**40**
29	590	556	**34**
30	582	556	**32**
31	580	556	**30**
Total height above ground level	**-**	**-**	**2886**

3.2 Physical and Mechanical Laboratory Test Results from both Federal University of Technology, Akure (FUTA) and Kaduna Polytechnic (KDP)

For the granite outcrop ‘A’ (SPB) with granite as a reference sample, there is presence of quartz, feldspar and dark mafic minerals (mica and hornblende), as well as fine grained texture. There is also no visible plane of weakness and they are free of defects. Quartz is the predominant mineral. Results of physical properties carried out on the granite samples from the two laboratories located in Kaduna (KDP) and Akure (FUTA) respectively are shown in the Tables 3 and 4.

The granite outcrop B (SPA) consists of quartz, feldspar and dark mafic minerals (including mica and hornblende). It has a fine grained texture with no visible plane of weakness. It is free of defects and quartz is the predominant mineral. The results of physical and mechanical properties of the laboratory analyses carried out on the samples from this outcrop are shown in the Tables 3 and 4.

Table 3: Summary of Physical and Mechanical Test

DEPOSIT A		
Test	**Kaduna Result**	**FUTA Result**
Average bulk density	2.805 gm/cm^3	2.79 gm/cm^3
Average Moisture Content	0.31%	0.26%
Average Crushing Value	21%	
Average Specific Gravity	2.92	2.84
Average Peak Stress		121.46MPa
Average Point Load Index		6.04MPa
DEPOSIT B		
Average bulk density	2.601 gm/cm^3	2.74 gm/cm^3
Average Moisture Content	0.34%	0.29%
Average Crushing Value	23%	
Average Specific Gravity	3.04	2.76
Average Peak Stress		156.29MPa
Average Point Load Index		6.14MPa

Table 4 Summary of Physical and mechanical Test Results in Comparison with Global Standards

Rock Property	ASTM Requirement	Outcrop A	Outcrop B
Specific Gravity	2.5 – 3.0 g/cm^3	2.84 g/cm^3	2.76 g/cm^3
Bulk Density	2.52 – 2.75 gm/cm^3	2.79 gm/cm^3	2.60 gm/cm^3
Moisture Content	0.1 – 0.2 %	0.31 %	0.3 %
Crushing Value	30	21 %	23 %
Peak Stress	200 - 131 MPa	121.46 MPa	156.29 MPa
Point Load Index	6.43 MPa	6.04 MPa	6.14 MPa

(Source: Anon., 2016; Olaleye, 2010)

3.3 Chemical Composition and Qualitative Characteristics of the Material

The description of the chemical composition of the granite outcrops is provided based on the findings of analytical studies of (four) 4 samples collected from the field during mapping. The findings of the chemical analyses of the samples showed that, within the estimated limits of the reserves, the minerals have the average chemical composition presented in Table 5.

Table 5 Average Chemical Composition of the Granite

Element	M1 (Outcrop 'B')	M2 (Outcrop 'A')
LOI	16.15	10.27
Al	9.48	9.42
Si	33.83	45.93
S	LOD	LOD
K	5.09	5.28
Ca	0.63	6.80
Ti	LOD	0.30
V	LOD	0.01
Cr	0.06	0.03
Mn	3.23	3.75
Fe	6.92	8.51
Ni	LOD	0.03
As	0.02	0.01
Se	0.15	0.07
Rb	0.03	0
Sr	0	0.01
Zr	0.54	0.31
Nb	2.75	1.40
Mo	0.01	0.01
Pb	LOD	LOD
Ag	LOD	LOD
Cd	LOD	0.09
Sn	3.71	0.64
Sb	2.34	3.87
Ba	0.06	0.05
W	6.78	3.12
Re	0.03	0.01
Au	0	0
Bi	0.01	0.03
Total	100	100

Note: *LOI means Loss on ignition; LOD means limit of detection*

3.4 Results of Petrographic Analysis

Major minerals present in the representative samples of the two outcrops are quartz, plagioclase feldspar, microcline and mica (biotite). The percentage modal compositions of the minerals of the two outcrops are shown in Table 6. From the petrographic/thin section results, it is found that outcrop A is a coarse grained granitic rock, while outcrop B is hornblende-biotite granite, thereby revealing their combined volumetric joint counts which make them potentially suitable for quarrying as suggested by Mbitsa and Idris (2018).

Table 6 Percentage Modal Composition of the Outcrops A and B

MINERAL	OUTCROP 'B' (%)	OUTCROP 'A' (%)
Quartz	45	40
Plagioclase	20	30
Microcline	25	-
Biotite	10	15
Hornblende	-	10
Opaque Mineral	-	05
TOTAL	**100**	**100**

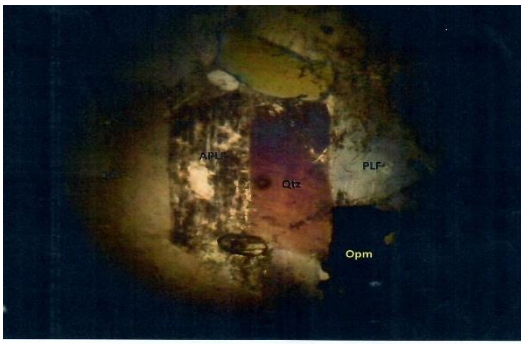

Fig. 12a Photomicrograph of Outcrop B under cross-polarize light

Fig. 12b Photomicrograph of Outcrop A under cross-polarize light

3.5 Discussion of Results

The results of the study showed that the values of all the parameters determined from the two granite outcrops (East and West) considered fall within the specified ranges of the globally accepted ISRM standards such as bulk density, moisture content, specific gravity, point load index, and uniaxial compressive strength. This assertion is corroborated by the research works of Adebayo *et al.* (2010), Korman *et al.* (2014), Naeem *et al.* (2014), Anon., (2016) and Olaleye (2010). Results from the uniaxial compressive test indicated that the rock outcrops are very competent for aggregate production and can be used for any engineering purposes. The results from the point load test also indicated that both outcrops are suitable for any engineering works. The brittleness test showed that the outcrops are moderately brittle and are, therefore, suitable for quarrying in agreement with the assertion adduced by Domede *et al.* (2017).

Petrographic/thin section results indicated that outcrop A is a coarse grained granitic rock, while outcrop B is hornblende - biotite granite. Also, the tests and examinations carried out on the representative samples from the two outcrops indicated that the rocks are found to be hard granitic rocks which can be used in monuments, ornamental (when cut and polished as dimension stone) and construction of any engineering structures.

Results from the study have, therefore, shown that the granite aggregates projected from the planned quarry production possess adequate physical and mechanical properties suitable for the following engineering applications: aggregates for concrete; construction of highways and dams; laying of structural foundation; construction of base and sub-base for railroad and airways; construction of mine openings/tunnels; construction of mole for breaking water; facing stone; production of artificial sand; and construction of protective blanketing for structure against erosion and dimension stones such as floor tiles, wall tiles, threads and riser, skirting, table top, bar top, and kitchen top. It is to be noted that the Eastern granite rock can also be cut and polished industrially to produce a kind of wall called granite wall.

Results of the study have shown that the tonnage of the two granite outcrops is estimated to be 150,102,190 tonnes. Based on proposed crusher capacity of 250 tonnes/hour, production schedule of 8 hours/day, 20 days/month and 12 months/year, and assuming an efficiency of 75%, the life span of the outcrops is determined to be 416 years, 11 months and 12 days.

4 Conclusions

The feasibility study on the suitability of granite outcrops for the proposed quarrying of aggregates at Kpoyipma community, Kaduna State, Nigeria, has been carried out and results have shown that the granite outcrops upon which feasibility study was conducted have all the required properties which make them suitable for engineering applications. Although the Western granitic dome is suitable for dimension stone, both outcrops are found to be aggregate materials. From the results, all the parameters upon which the two granite outcrops (East and West) were appraised have been found to fall within the specified ranges of the globally accepted standards of the American Standard for Testing Materials (ASTM, D 2487) and International Society for Rock Mechanics (ISRM, 1985).

From the results of survey and estimation, the two granite outcrops are thus found to be economical for the proposed quarrying operation thereby making the project of utmost importance to the host community. The mineral development therein will also improve the social-economic value of the domiciled area and the nation at large by providing better employment opportunities and improvement in social infrastructure of the area, apart from increased financial benefits accruing to the government through taxes, royalties and other sources of revenue.

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