

## Estimation of Reserve-Overburden Ratio of a Proposed Quarry Site Using Resistivity Survey: A Case Study of Ajebo, near Abeokuta, Southwestern Nigeria

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**Abstract:** The geophysical and geotechnical assessment of the granite deposit at Idi-Osan Ofagada village near Abeokuta, southwestern Nigeria was undertaken to establish the suitability of the deposit for exploitation. Fourteen Vertical Electrical Soundings (VES) were carried out on the areas covered with overburden to determine their resistivity characteristics, overburden thickness and the reserve tonnage of the basement rock. The compressive strength and the specific gravity of the rock were also determined. The area is gridded into 5 by 6 blocks for more accurate calculations of the parameter for the estimation of the reserve. The reserve estimates to elevation datum of 150m, 160m and 170m were determined. The VES results showed a two to three geoelectric layers; the sandy weathered layer, clayey layer and the basement. The isopach and geoelectric sections revealed that the overburden thickness varies from 1.5m to 23.6m with the thickest overburden of =10m occurring in the north-western and south-eastern parts. The compressive strength, Young Modulus and specific Gravity are respectively  $47.68\text{N/mm}^2$   $633\text{N/mm}^2$  of 1.615. The reserve estimates for 170m, 160m and 150m elevation datum are  $4.42 \times 10^5$ ,  $17.17 \times 10^5$  and  $37.09 \times 10^5$  tons respectively. The rock-overburden ratio indicates that quarrying of the rock is economically viable most especially at 160m and 150m datum.

**Key words:** VES • Reserve Estimation • Specific Gravity • Overburden Thickness

### INTRODUCTION

The recent growth in populations in Abeokuta town and its environs has imposed significant stress on the existing inadequate building materials for construction. Consequently, it became very expedient to expand the existing quarry sites in the area as a result of the daily increase in the demand of crushed granite for building construction. This has caused the need for the exploration for more competent rocks to serve as quarry sites so as to meet this ever increasing demand.

Different authors have established the economical importance of the southwestern basement complex of Nigeria [1-5] and this complex has been found out to serve as good hosts to different mineral deposits and most importantly as a good material for civil constructions. Apart from the geochemical studies of this complex [6, 7] they have also been explored using geophysical methods [8-11], while some authors had used these geophysical methods in the estimation of these complex reserves [12-14].

A number of factors determine whether a rock can be quarried for construction. These include the volume of material that can be quarried, the ease with which it can be quarried; the wastage consequent upon quarrying; and the cost of transportation; as well as its appearance and physical properties [15]. Furthermore, the volume must sustain not less than 20 years of quarrying [16]

The aims of this work are to carry out the geophysical and geotechnical assessment of the rock deposit at Idi-Osan, Ofagada village near Abeokuta and to evaluate the geological parameters that will influence the economic viability of the quarrying the rock mass. This is done by the study of the resistivity variation characteristics of the subsurface in the area, to determine the overburden thickness. This is complemented by the determination of the specific gravity and uniaxial compressive strength and eventually, reserve tonnage is estimated.

**The Location and Geology of the Study Area:** The study area can be assessed by the tarred Abeokuta - Ajebo road and the site is located about 2km off the tarred road.

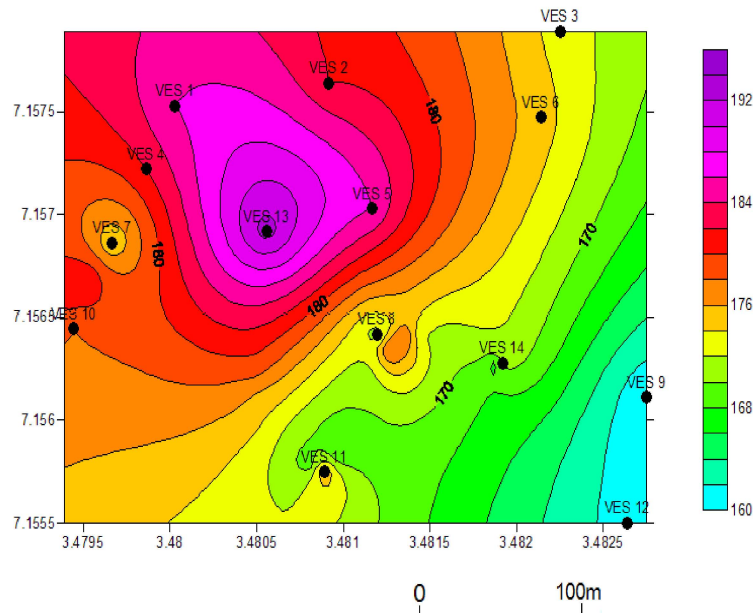


Fig. 1: The Location Map showing the Elevation and VES survey of the study area

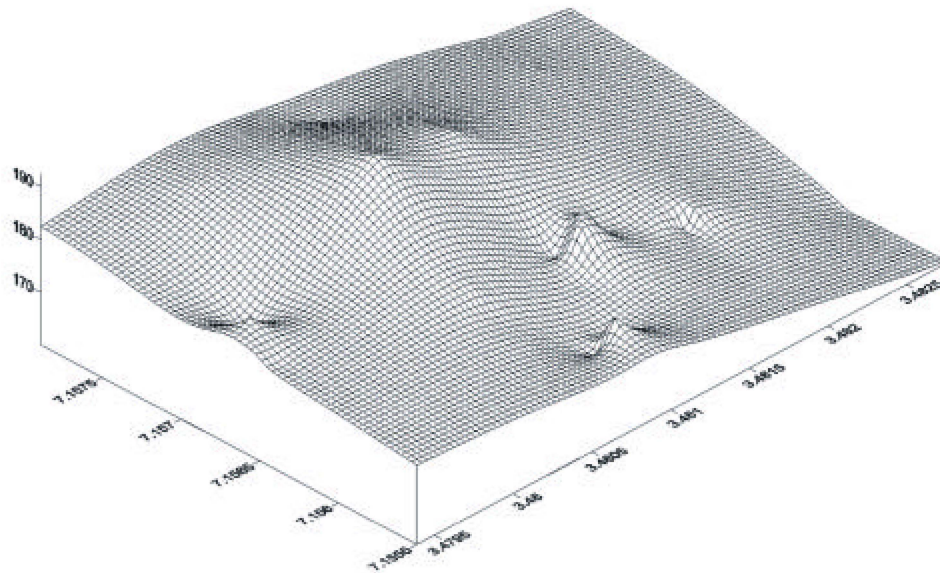


Fig. 2: The 3D of the topography of the study area

The site lies between co-ordinates 07.1555°N-07.157889°N and 003.479389°E - 003.48275°E (Fig. 1). The location of the rock mass is far from human settlements and highways and the 3D of its topography is shown in Fig.2. The climatic condition of the area is tropical rain belt as typical of southwestern Nigerian and expressed a contrast between the dry and wet seasons. It is characterized by very high rainfall, low pressure, high precipitation, high evaporation and relatively high humidity. The dry season is between November-March and we season is between

March-November. Annual rainfall is about 1500mm [17]. A relatively low amount of rainfall is recorded in August due to little dry season other wise called August break, which is a form of climate anomaly through Nigeria. [18]. Temperature ranges from a mean maximum of 32°C in February to a mean minimum of about 21°C in August. This high temperature, coupled with high rainfall, is likely to enhance or promote weathering [19]. The topography is generally undulating; the highest elevation is about 192m, which was recorded

almost at the centre of the lease while the lowest elevation is about 160m in the southeast. The area lies within the Precambrian Basement of South-Western Nigeria. The study area is exclusively underlain by granite gneiss and this rock has been crosscut by the quartz and pegmatite veins. There is also evidence of fractures observed.

**Methodology:** The elevation measurements of the area were made using the Garmin 76 Global Positioning System (GPS), with a view to determine the spatial distribution of the rock mass. The GPS was also used in the location of the VES and sample points and this helped in the production of maps and other interpretations.

**Geophysical Investigations:** The geophysical investigation was carried out using the ABEM SAS 300C Terrameter. This equipment is equipped with an in-built digital display and recording system. Rechargeable 12-volt batteries coupled to the equipment provide the energy for the equipment operation.

Schlumberger array method was used for the VES data acquisition and is capable of isolating successive geoelectric layers beneath the surface and a maximum current electrode spacing ( $AB/2$ ) of 15m to 80m was used throughout the study based on the nearness of the basement in each location with potential electrode spacing of between 0.25m and 2.5m while equally maintaining the potential electrode and current electrode geometric relationship at  $MN = 1/5 AB$  [20]. The instrument displays the resistance of the area and the result was multiplied by its Geometric Factor to calculate the apparent resistivity of each point. The values obtained were then plotted on a log-log paper as points with the apparent resistivity values being on the vertical axis and the electrode spacing ( $AB/2$ ) on the horizontal axis. The field curves were manually interpreted [21], using master curves [22] and auxiliary point charts [23, 24]. Geoelectric parameters obtained from manual interpretation were then used as an in-pu-t model for computer-aided iteration of WINRESIST Program for the interpretation [25] until it finds a final geoelectric model that is satisfactorily best of fits for the data.

Fourteen VES surveys were conducted around the study area as shown in Fig. 1 to determine the overburden thickness and these were carried out and spread across to areas where the overburden is covering the basement.

**Geotechnical Investigations:** Block samples of the Idi-Osan Ofagada granite were investigated for the suitability of the rock as a building and construction material.

The uniaxial compressive strength of the rock blocks was determined using the Universal Testing Machine (UTM) model AXM500-50KN. The specific gravity of the rock was also measured to calculate its tonnage in the laboratory of Department of Civil Engineering, University of Ilorin, Nigeria.

**Reserve Estimation:** The tonnage estimate is derived from elevation, the rock density and the overburden thickness of the area. Gridding method was adopted in this exercise, the area was divided into 5 by 6 grids and average elevation was calculated for each grid. The length and breath of each grid were measured to be 62m and 52.3m respectively.

## RESULTS AND DISCUSSION

**Geotechnical Interpretation:** The calculated uniaxial compressive strength of the rock blocks gave an average value of  $16.67\text{N/mm}^2$ , this falls within the class of moderately strong as classified by [26]. The foliation in the rock may be responsible for the significant loss in strength compared to granite; however, the strength is still adequate for materials to be used as construction aggregate. The engineering performance of gneiss is usually similar to that of granite; the presence of foliation does not significantly affect it engineering behavior [16].

**Geophysical Interpretations:** The VES resistivity results for the 14 locations were plotted and interpreted. A typical VES curve in this area is shown in Fig. 3. The geoelectric sections along Traverses 1, 2 and 3 are shown in Fig. 4a-c. The sections showed that the area is predominantly made of 2 geoelectric layers, i.e. the weathered layer and the basement rock, the weathered layers are mainly sandy and there is also occurrence of clay especially in Traverse 1. The resistivity range of the weathered layer varies between  $53 \text{ }\Omega\text{m}$  to  $3950 \text{ }\Omega\text{m}$  and has thickness range of 1.5 to 17.4m while the basement resistivity ranges from  $380 \text{ }\Omega\text{m}$  to  $16252 \text{ }\Omega\text{m}$ . The interpreted depths to the bedrock obtained in the different VES stations were plotted and contoured to produce the isopach map of the area (Fig. 5) and the average overburden thickness was calculated for each grid of the area and is presented in Fig. 6. These showed that the thickness varies from 1.5 m to 23.6 m. The thickest overburden is observed at the north-western and south-eastern parts while relatively thin (under 7 m) overburden were observed at the central-north, western and eastern parts.

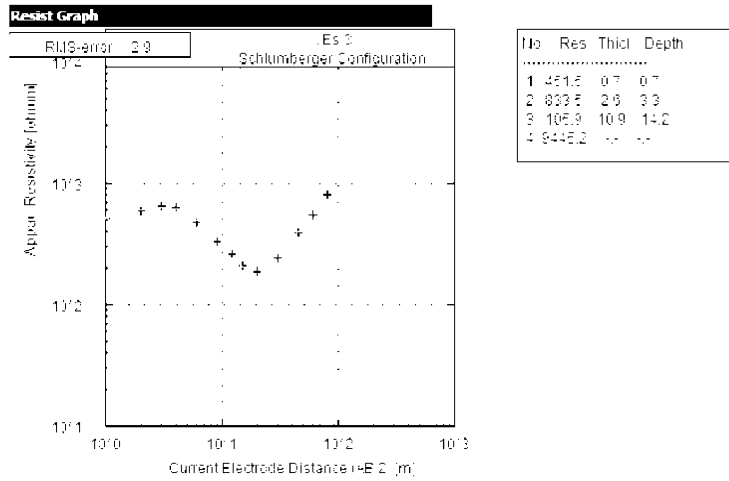


Fig. 3: A typical Iterated VES curve in the study area

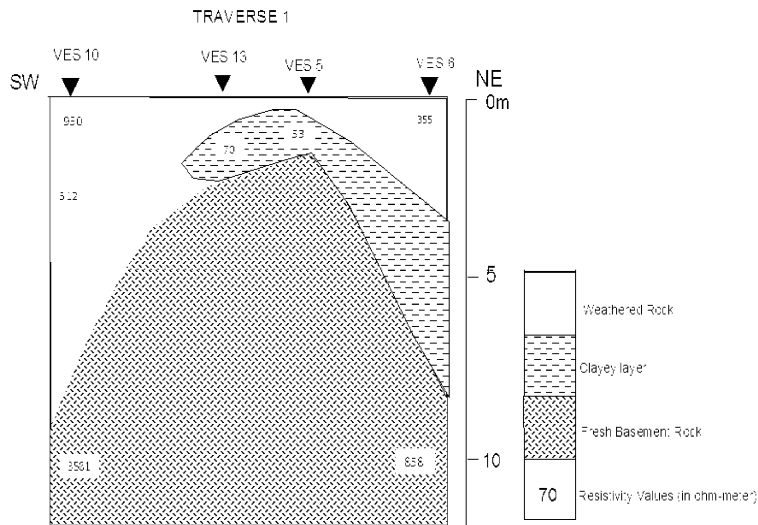


Fig. 3a: The Goelectric section across Traverse 1 in the study area.

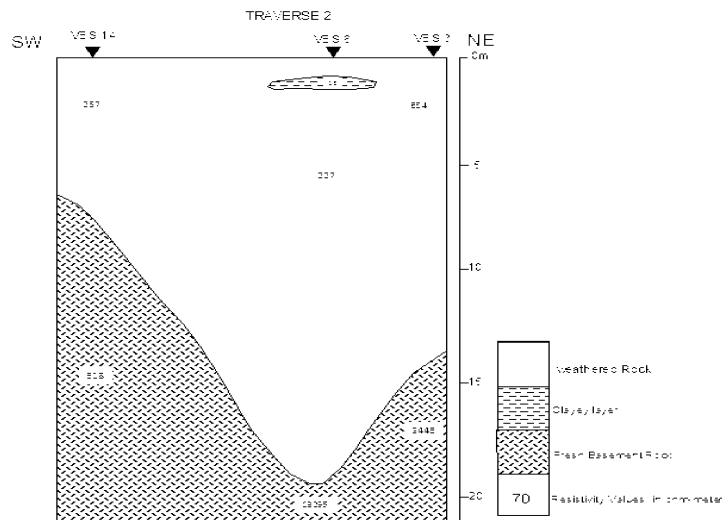


Fig. 4b: The Goelectric section across Traverse 2

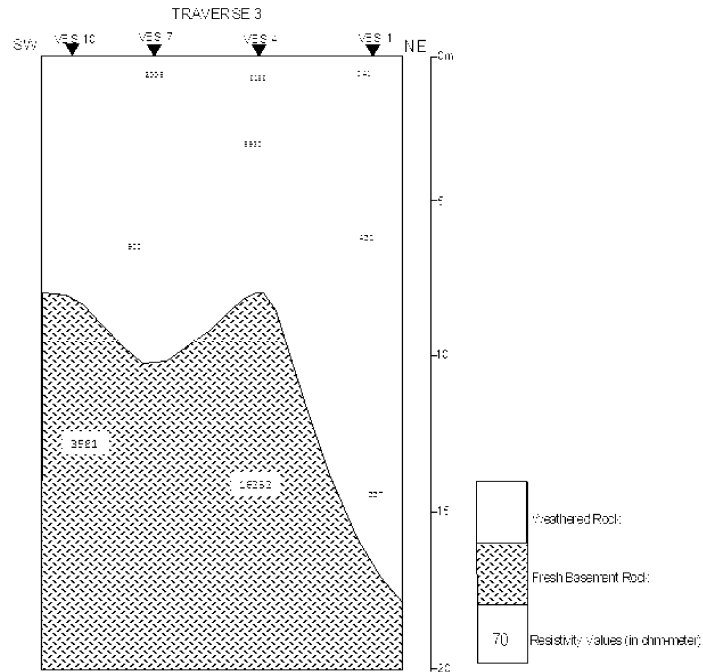


Fig. 4c: The Geoelectric section across Traverse 3

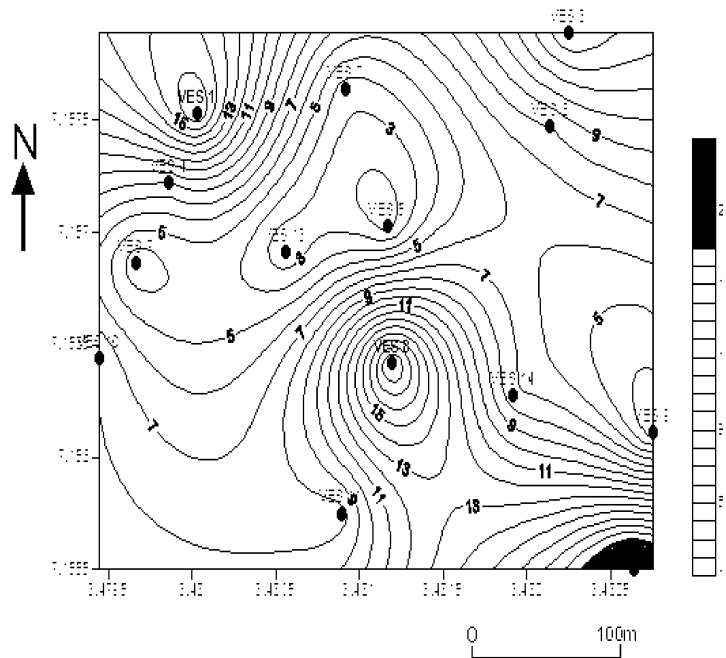


Fig. 5: The isopach map of the overburden thickness in the study area

**Calculation of Reserve:** The average overburden thickness in each grid was subtracted from the corresponding average elevation grid and the result was shown in Fig. 7. The result represents the top surface elevation (Ordinance Datum) of the underlying fresh bedrock in the area.

i.e.  $OD = \sum (\overline{EG} - \overline{OT})$  where OD is the ordinance datum,  $\overline{EG}$  is the average Elevation Grid and OT is the average overburden thickness. The lowest ordinance datum observed in the grid is 138m while the highest is 184.2m. The average thickness of the overburden over the whole lease area is 9m; this is of course rather high overburden

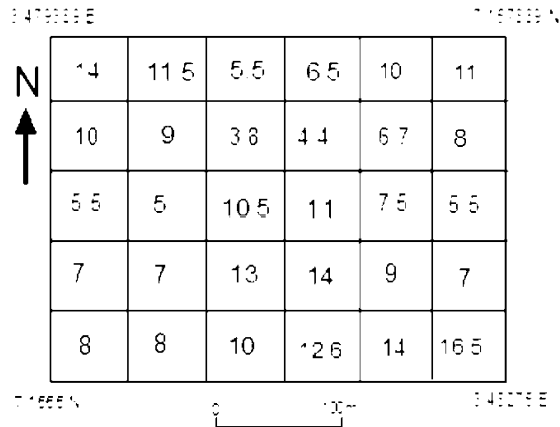


Fig. 6: The average overburden thickness for each grid in the study area

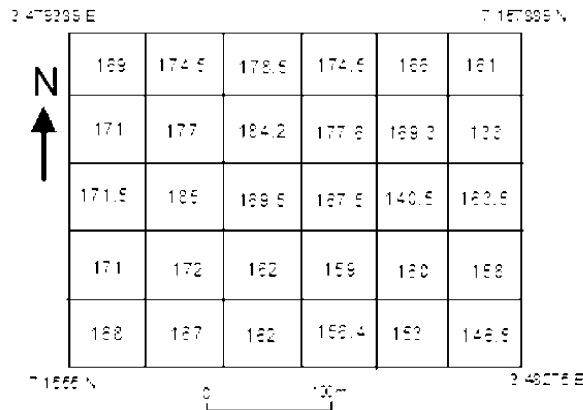


Fig. 7: The average residual elevation after the removal of the overburden thickness

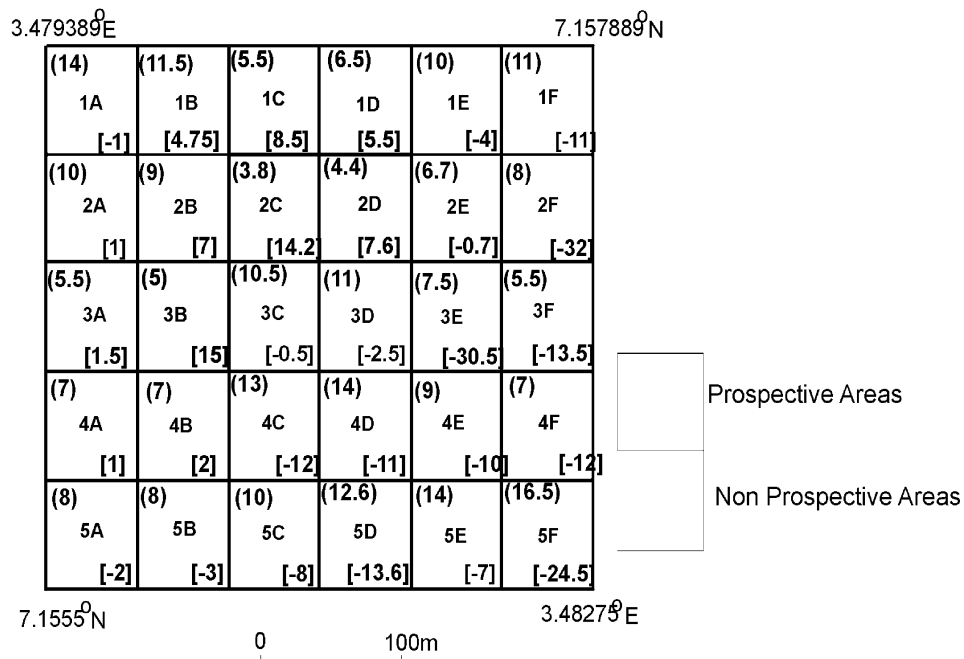


Fig. 8: The average thickness of overburden (in bracket) and granite body [in square bracket] at 170m datum

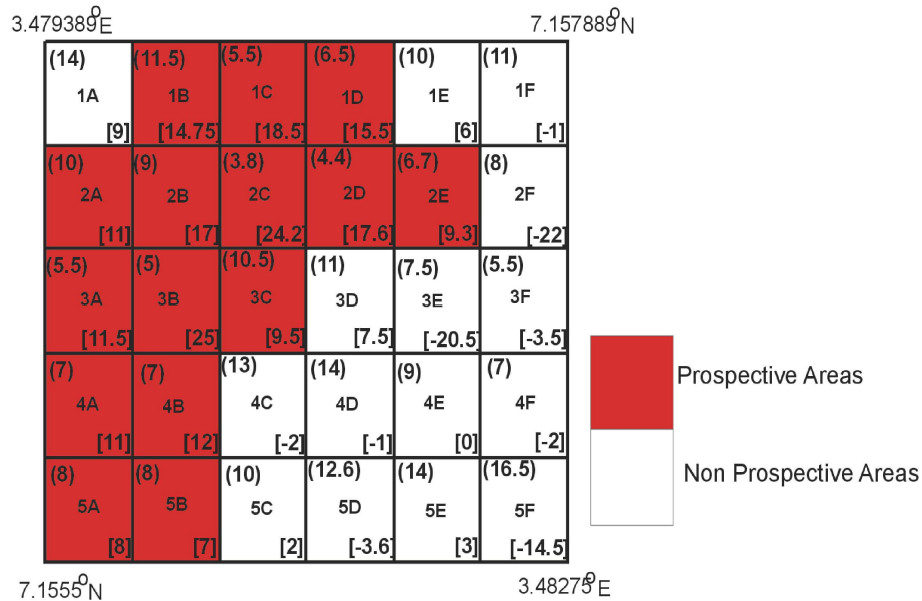


Fig. 9: The average thickness of overburden (in bracket) and granite body [in square bracket] at 160m datum

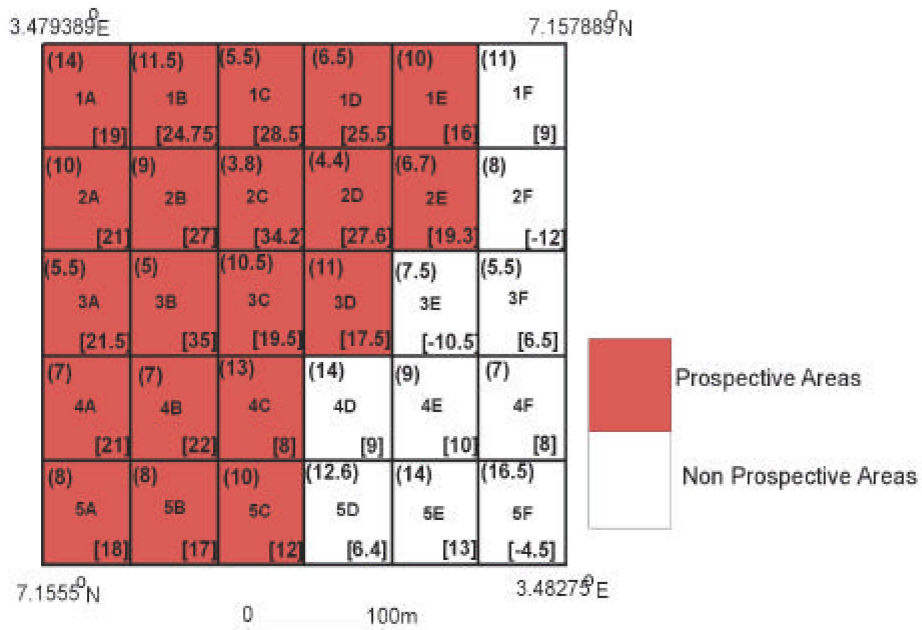


Fig. 10: The average thickness of overburden (in bracket) and granite body [in square bracket] at 150m

thickness especially when the cost of removing it is put into consideration for profitable quarrying. Therefore, there is the need for selection and consideration of parts of the study area that are economically viable for exploitation. The criterion employed for area selection for the reserve estimation is such that the minimum ratio of overburden thickness to rock thickness is ratio 1:1. Three levels of reserve estimate could be made taking the rock

base to be at successively lower ordinance datum of 170m, 160m and 150m. Figures 8, 9 and 10 show average thicknesses of the overburden and the thicknesses of the fresh rock body at the specified ordinance datum in the area which has been split into thirty (30) grids and were labeled 1A to 5F (i.e. at OD of 170, 160 and 150m respectively). The average thickness of the overburden is in parenthesis while the thickness of the rock is in square

Table 1: Summary of Overburden and Granite Reserve Estimates

Elevation Datum ( m )	Granite Thickness (m)	Granite Reserve Estimate ( tons )	Overburden Thickness (m)	Overburden Volume (m <sup>3</sup> )	Rock Mass Reserve/Overburden Volume Ratio	Granite Thickness/Overburden Thickness Ratio	Duration of Reserve at 250 tons per day (yr)
170	51.1	442,410.62	25.2	81,713.52	5:1	2:1	6.7
160	198.35	1,717,263.13	108.4	351,606.24	5:1	2:1	26
150	428.34	3,708,543.79	166.4	539,568.68	7:1	2.6:1	56

bracket. Each grid is 62m by 52.3m or 3,242.6m<sup>2</sup> area extents. The grids that meet the above criterion were shaded and the volume of the reserve was calculated using the formula:

$$\text{Reserve Volume (m}^3\text{)} = \Sigma (\text{area grid (m}^2\text{)} \times \text{average thickness of grid (m)})$$

**The Reserve Tonnage Is Therefore Calculated By:** Reserve Tonnage (tons) =  $\hat{O}$  (volume grid (m<sup>3</sup>) x specific gravity of the rock).

The reserve estimate calculations for these three ordinance datum were recorded in Table 1 and showed that the reserve estimate for economically viable grids for 170m, 160m and 150m are 4.42 x 10<sup>5</sup>, 17.17 x 10<sup>5</sup> and 37.08 x 10<sup>5</sup> tons respectively. Although high volumes of overburden need to be removed to get to the fresh basement at the different elevation levels, the prospective granite tonnage is significantly very high to ensure satisfactory profitability following the criteria stated above.

**The Rock Mass to Overburden Thickness Ratio and Duration:** The cost of removing the overburden thickness should be considered in mining of rocks. It is important to take into cognizant the economic viability of the mining. The rock: overburden thickness ratios of 1 to 1 very much satisfy the universal profitability factor of thickness ratio of 0.5 for mineral deposits. Though the overburden materials are not waste as they could be excavated and marketed as ‘bulk-fill materials’, where their thickness is more than the rock thickness are not considered in order to minimize the cost of removing the overburden, environmental implication and profitability. This will very much assist to mitigate the cost of accessing the fresh granite gneiss in areas with thickness lower than the rock thickness. The quarrying of the rock could thus be undertaken in stages to target the above considered 170m, 160m and 150m ordinance datum. Table 1 also shows calculation of the rock mass : overburden thickness ratios in these three data and revealed a ratio of 2 to 2.6, which very much satisfy the universal profitability factor of thickness ratio of 0.5 for mineral deposits. [15,16]. Apart from considering the rock mass to overburden thickness

ratio, the life span of the reserve is also very important. For a reserve to be considered to be economically viable, the volume must sustain not less than 20 years of quarrying [16]. However, in this area, if an exploitation rate of 250 tons per day is adopted, the duration for exhausting the reserve estimates will successively be 6.7years, 26years and 56years for the adopted ordinance data of 170, 160 and 150m respectively. This however makes the ordinance datum of 150 and 160m to be good and suitable for mining when their economic viability is considered.

### CONCLUSION

The Idi Osan Ofagada granite gneiss has been evaluated with careful consideration for rock mass: overburden ratio using three different ordinance data of 170m, 160m and 150m to estimate the tonnage with careful consideration of economic viability. The rock mass possess geotechnical properties comparable to competent rocks commonly exploited as aggregate materials.

The closeness of the location to Lagos (one of the world top 10 most populous city) is an advantage on cost of transportation. The rock as is largely fresh, though its fractured nature will limits its used in the production of dimension stone. Nevertheless it’s moderately strong strength suggests that it can be used as aggregates for construction works. Areas with minimum ratio of granite gneiss to overburden thickness of 1:1 are assessed to be suitable for exploration.

Furthermore, the volume of reserve that can be quarried from the area is to 26 to 56 years at ordinance datum of 160 and 150 respectively when quarrying of 250tonnes is done per day, hence the rock mass is economically viable for quarrying as construction aggregates.

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