International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Volumetric Analysis of Minable Crystalline Rocks using Resistivity Survey at Old Netim Quarry, Akamkpa, Cross River State, Nigeria

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A B S T R A C T

Looking to estimate the volume of crystalline rocks that can be mined in a given quarry, vertical electric sounding (VES) was done to aid the analytical process required to make the needed estimates. Schlumberger electrode array was employed during the VES process. Six vertical electrical soundings were carried out with a maximum electrode spreading of 120m, which corresponds to a total investigated depth of 40m. Due to the rugged terrain in the site of investigation, the sampling interval was not constant, ranging from 149m to 589m, with a total survey area of approximately 84,978m^2. The apparent resistivity data obtained from field measurements were interpreted using the IPI2Win Software. The area surveyed was been found to be highly prolific in terms of the availability of minable crystalline rocks used for construction purposes. The basement and overburden rocks were estimated to be 34.85m and 2.44m thick, respectively. The volume of extractable crystalline rock in the surveyed area is two million nine hundred and sixty-one thousand four hundred and eighty-three cubic meters. The volume of overburden estimated to be removed in the surveyed area is two hundred and seven thousand, three hundred and forty-six cubic meters. It is furthermore recommended that the depth below 40m be investigated in the future to determine the occurrence of minable basement rocks.

Keywords: Mineable, Crystalline, Resistivity, Quarry, Basement, Overburden

1. Introduction

Any rock type that is fully made of crystallized minerals, free of glassy material, is commonly referred to as crystalline rocks (Gill & Fitton, 2022). Extrusive igneous rocks, or volcanic rocks, can range from partially to completely glassy, whereas intrusive igneous rocks—those that solidify at depth—are almost always crystalline (Jerram & Petford, 2011; Sen, 2014). Although there are other influencing factors (Brattli, 1992; Brigatti & Gregnanin, 1987; Davidson et al., 2007), the duration of cooling is the main determinant of a magma's ability to crystallize (Cáceres et al., 2021). There are many different igneous and metamorphic rock types in the crystalline rock environment. Their crystallization histories determine the compositions of igneous rocks as well as many of their physical characteristics (Blatt et al., 2006; Gill & Fitton, 2022).

The Earth's solid bedrock contains the highest concentrations of crystals, both in terms of volume and mass (Prothero & Schwab, 2004). Although exceptionally big crystals are occasionally discovered, most crystals found in rocks are between a few microns and a few centimeters in size (Cashman & Ferry, 1988; Sprunt & Brace, 1974).

Techniques for measuring geophysical resistivity are based on how the earth reacts to an electrical current flowing through it (Gallas et al., 2011; Sumner, 2012). The electrical impedance of the volume of subsurface material being probed is measured employing techniques which involve passing an electric current via two current electrodes and two potential electrodes placed in between to record the consequent potential difference between them. The measured impedance (ratio of potential to current) and the electrode array's geometry together determine the perceived resistivity (Jaja et al., 2021; Seidel & Lange, 2007). Since the earth is anisotropic relative to its geophysical measures, the measured resistivity is said to be *apparent* (Habberjam, 1975; Samouëlian et al., 2005).

The presence of water in the shallow subsurface greatly influences the fluctuations in conductivity. Resistivity, which is the inverse of conductivity, is typically used to gauge water saturation, porosity, and permeability (Huntley, 1986; Khalil & Monterio Santos, 2009; Wang et al., 2016). This is due to the fact that dissolved ions in solution are principally responsible for the subsurface's electrical conductivity (electrolysis). Thus, as seen in typical sedimentary

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rocks, a rise in ions concentration (salinity), porosity, and permeability tend to lower measured resistivity (Ammar & Kamal, 2018; Garrouch & Sharma, 1994). On the other hand, crystalline rocks are predicted to have a wide range of resistivity values (as seen in Fig. 1) since they have little intergranular porosity (Pola et al., 2012; Tullborg & Larson, 2006). Considering the aforementioned, geophysical resistivity techniques can be used to map the distribution and occurrence of basement rocks.

Numerous granite quarries have been established by investors for the production of rock aggregates due to the increasing demand for crushed rocks as construction materials in Nigeria's Cross River State and other parts of the country (Amah et al., 2012). Basement rocks are known to exist in the Oban and Obudu districts of southeast Nigeria (Ekwueme, 1990). When mined, these rocks could offer economical raw materials for use in civil engineering. The quarrying project, however, requires a lot of finance. Therefore, it is crucial that material qualities be assessed to help investors avoid losing money up front only to discover later that the material's quality and quantity at the quarry sites are inadequate for some desired objectives. This research was therefore embarked on to estimate the amount of crystalline rocks that can be mined at the study area by carrying out geophysical electrical resistivity investigation.

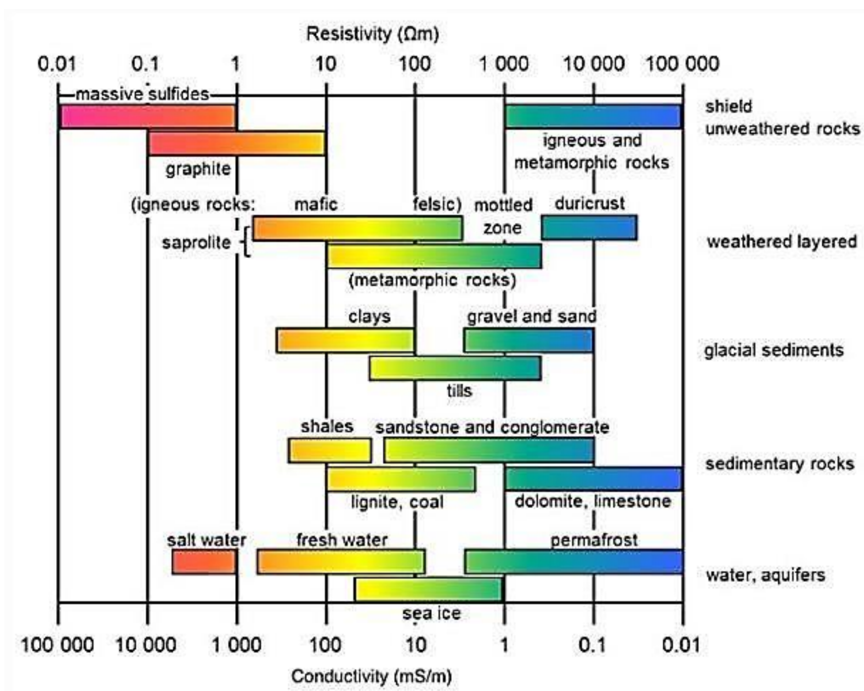


Fig. 1: Electrical conductivity and resistivity of common rocks (Telford et al., 1990)

2. Physical Setting and Geology of Survey Area

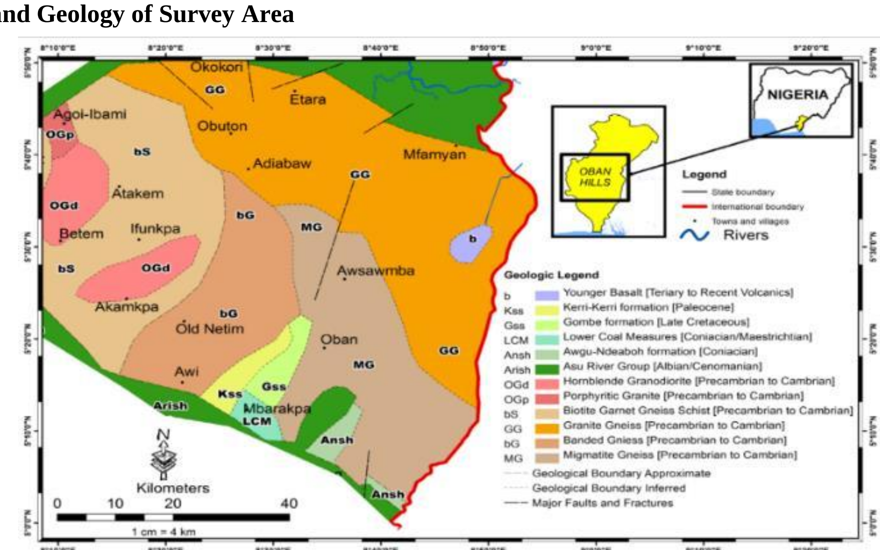


Fig. 2: The Geologic map of the study area (Amah et al., 2012)

Old Netim is a village located on a hilly rainforest terrain north of Akamkpa town (See Fig. 2). As a result of the abundance of crystalline basement rocks in the area, a lot of mining companies are operating quarries there. Wood logging and farming activities were also observed, due to the presence of a thick equatorial rainforest and fertile arable lands. The area is crisscrossed by quite a number of streams originating directly from ground water seepages.

Geologically, Old Netim belongs to the Precambrian basement complex of Oban Massif (Rahman & Ukpong, 1981). The Oban Massif occupies about 10,000km^2 in Southeastern Nigeria and includes such mappable metamorphic rock units as phyillites, schists, gneisses and amphibolites (Amah et al., 2012; Rock et al., 2017). The rocks are intruded by pegmatites, granites, granodiorites, tonalities monzonites and doelrites (Ekwueme, 1990). The oldest rocks in the Oban Massif are the banded gneisses, and the youngest rocks are believed to be dolerites. The most conspicuous intrusive rock in the Oban Massif is granodiorite which is well exposed in Old Netim. Kyanite gneiss is the predominant gneiss in the Old Netim area (Ekwueme, 1987).

3. Methodology

Field Equipment

The field equipment for this survey includes Chauvin Arnoux Terca 3 earth resistance tester with an in-built 12.5 V battery, non-polarizing electrodes (four pcs), hammer, measuring tape, cable reels, communication gadgets, field notebook and biro, GPS and camera.

Electrical Resistivity Survey Method

A generalized field configuration for the employed resistivity survey is shown in Fig. 3.

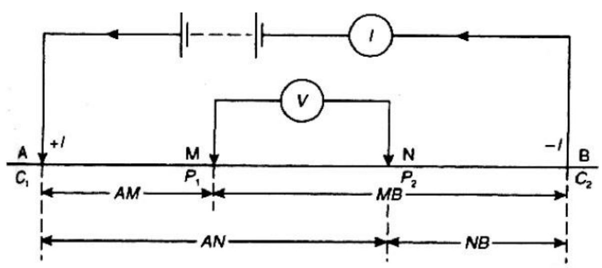


Fig. 3: Generalized field configuration

The nature of the spatial arrangement of electrodes gives rise to the different field configurations in resistivity surveys. The suitability of anyone preferred, depends on the equipment being used, the geology of the study area, the purpose of the survey and logistics of the field work (Okpoli, 2013; Seidel & Lange, 2007). Some of the popular configurations include Schlumberger, Wenner, Dipole-Dipole, Pole-Dipole, Lee – Partitioning array etc. However, in this research project, Schlumberger array was used, because it has comparative advantage over the rest, in terms of its higher sensitivity to changes in resistivity with depth and logistics ease (Okpoli, 2013). In Schlumberger array, four electrodes are positioned symmetrically in a straight line as shown in Fig. 4. Current is sent into the ground via the current electrodes, AB, and the potential difference between the potential electrodes, MN, is recorded. After each measurement, the current electrodes are moved outward, relative to the potential electrodes. In order to maintain a measurable potential at large distances of current electrodes, it is necessary to expand the potential electrodes after a series of measurements.

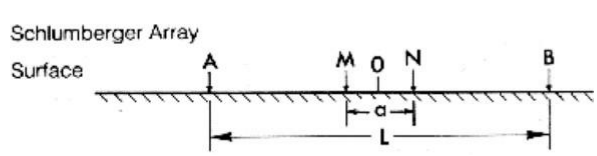


Fig. 4: Schematic of Schlumberger array

Typically, the relationship between the current electrode spacing and potential electrode spacing is such that MN less than or equal to 20% of AB (Binley & Kemna, 2005). Apparent resistivity, ρ_a, is calculated from schlumberger array using the mathematical relationship;

$$\rho_a = \left[\frac{\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2}{MN}\right] \times \pi \left[\frac{\Delta V}{I}\right] \quad (1)$$

Field Data Collection

Six vertical electrical soundings were carried out using the Schlumberger method, and their positions flagged by noting their coordinates with the aid of a GPS survey device. A maximum electrode spread of 120meters was employed and this corresponds to a total investigated depth of approximately 40meters. The sampling interval was not constant due the rugged terrain; it ranges from 149 meters to 589 meters. The survey lines were oriented in the NE – SW direction in line with the orientation of the dominant tectonic features in the region. The total surveyed area is approximately 84,978m^2 and a sketch of the layout of the area is shown in Fig. 5. The elevation ranges from 115.4m to 149.7m above mean sea level giving the area a north-eastward slope.

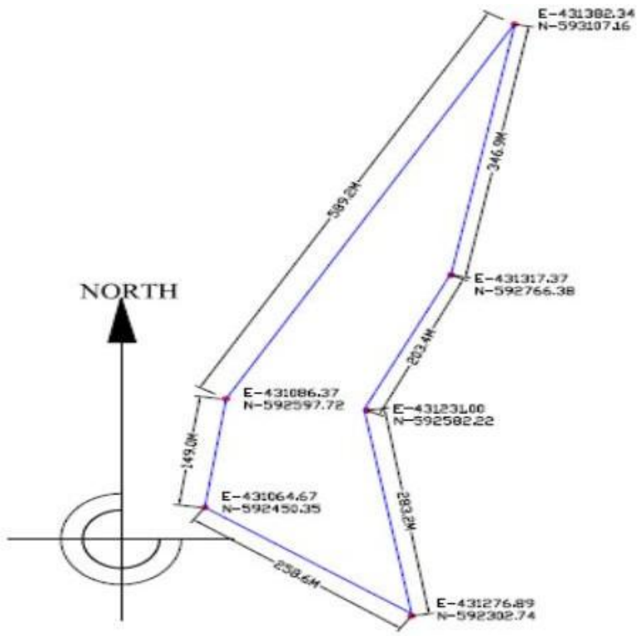


Fig. 5: Layout of Survey Area

Volumetric Estimates

The volume of minable crystalline basement rock in the area was calculated thus;

$$Volume\ (V) = Total\ Surface\ Area\ (A) \times Average\ Thickness\ of\ basement\ (H) \qquad (2)$$

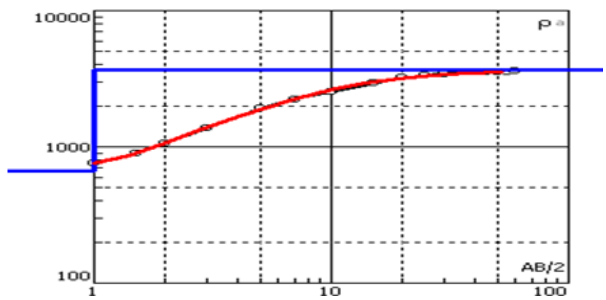
4. Results and Discussion

Estimates of Overburden and Basement Thicknesses

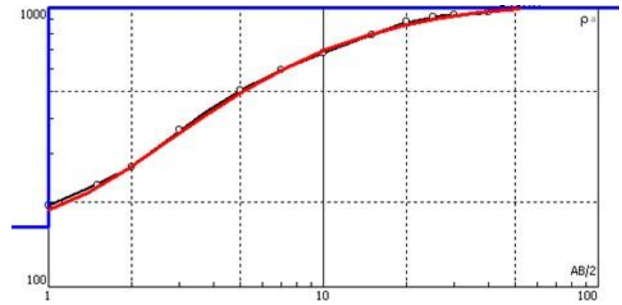
The apparent resistivity data obtained from field measurements were interpreted using the IPI2Win Software. An inversion procedure has to be applied to convert the measured apparent resisitivities to true resistivities in order to have the correct geological interpretation of the geo-electric features of the area. A cross-plot of the apparent resistivity and current electrode spacing resulted in a regression curve that was calibrated with a predefined earth resistivity model which represents the true resistivity of the earth. A line of best fit with minimal errors was thereafter obtained. It is from these calibrated curves that the true earth resistivity distribution of the area surveyed was determined. The results of the VES are presented as geo-electric sections of the true resistivity distribution with two interpretable layers. See Fig. 6 and table 1 below.

The overburden consists of lateritic clays and intensely weathered basement materials, while the basement is made up of crystalline metamorphic rocks chief of which is kyanite gneiss with granodiorite intrusions. The resistivity distribution of the various lithologic layers as well as the calibrated sounding curves can be seen in the appendix. The thickness of the overburden ranges from 0m to 10m while that of the basement is about 26.7m to 39m. Whereas the overburden is generally thin and virtually absent just as in VES3 and other sounding locations, it was curiously thick at VES2. The reason for this observation is that VES2 is located in a depression adjacent to a running stream. This stream is believed to have permeated deep into the basement rock resulting in intense weathering and fracturing. The fractures and joints are filled with fresh water, hence the very low resistivity values and thick overburden. See appendix. At VES3, the crystalline basement starts from the surface, with negligibly thin soil cover. But at depths of 26.7 to 36.7m, the basement rock intercepts and underground stream resulting in intense fracturing. But below 36.7m, the crystalline basement begins to show up again down to the maximum investigation depth of 40m.

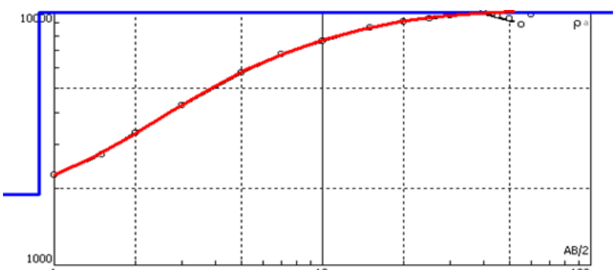
At the remaining VES stations, the general pattern of thin overburden and thick crystalline basement is observed

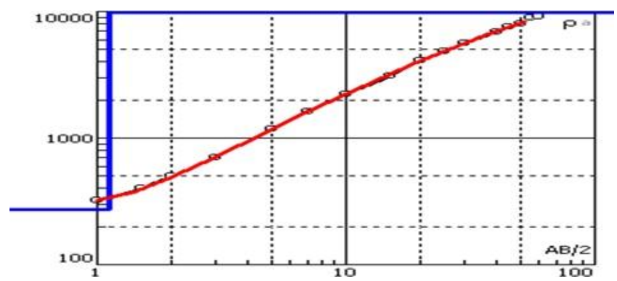


VES 1

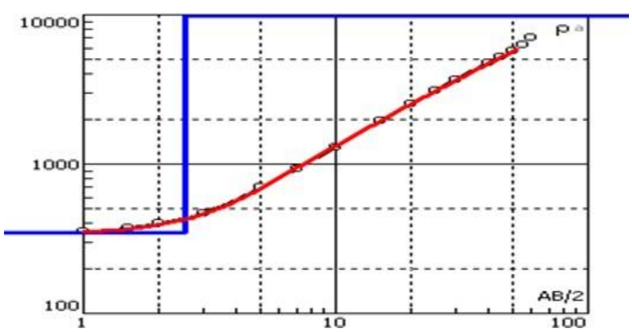


VES 2

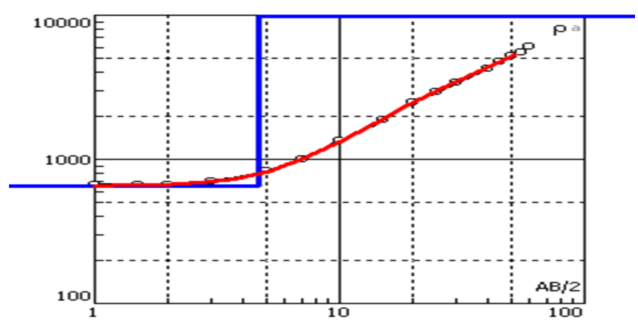




VES 4



VES 5



VES 6

Fig. 6: Resistivity Sounding Curves for the Six (6) Surveyed Locations.

Table 1: Geologic interpretation of theGeo-Electric Models

S/N	SOUNDING POINT	COORDINTATE		OVERBURDEN		BASEMENT	
		EASTERN (m)	NORTHERN (m)	DEPTH (m)	THICKNESS (m)	DEPTH (m)	THICKNESS (m)
1	VES 1	431276.89	592302.74	0 – 1.0	1	1-40	39
2	VES 2	431064.67	592450.35	0 – 10	10	10 - 40	30
3	VES 3	431086.37	592597.72	-	-	0 – 26.7	26.7
4	VES 4	431231.00	592582.22	0 – 2.0	2.0	2 - 40	38
5	VES 5	431317.37	592766.38	0 – 3.3	0.33	3.3 - 40	36.7
6	VES 6	431382.34	593107.16	0 – 1.3	1.3	1.3 – 40	38.7

Volumetric Analysis

The volume of minable crystalline basement rock, V_B, in the area was calculated using equation 2, where $A = 84{,}978m^2$ (the total surveyed area) and $H = 34.85m$ (the average of the estimated thickness of the basement). Hence,

$$V_B = (84{,}978 \times 34.85)m^3 = 2{,}961{,}483.3m^3$$

In other words, the volume of extractable crystalline rock in the surveyed area is two million nine hundred and sixty-one thousand four hundred and eighty-three cubic meters.

Additionally, the quantity of overburden, V_O, expected to be removed can also be estimated from equation 2, where $A = 84{,}978m^2$ (the total surveyed area) and $H = 2.43m$ (the average of the estimated thickness of the overburden). Therefore,

$$V_B = (84{,}978 \times 2.44)m^3 = 207{,}346.32m^3$$

In other words, the volume of overburden estimated to be removed in the surveyed area is two hundred and seven thousand, three hundred and forty-six cubic meters.

Evidently, the basement is quite shallow and the overburden relatively thin, making it economically easier to mine according to Wagner and Schomann (1991).

5. Conclusion

This research work was carried out to estimate the volume of crystalline rocks that can be mined in the investigated site. To this end, Vertical Electric Sounding (VES) was carried out in the investigated area, employing Schlumberger electrode array. Data obtained was then analysed and the following conclusions were arrived at;

i. The area surveyed was been found to be highly prolific in terms of the availability of minable crystalline rocks used for construction purposes.
ii. The basement and overburden rocks were estimated to be 34.85m and 2.44m thick, respectively.
iii. The volume of extractable crystalline rock in the surveyed area is two million nine hundred and sixty-one thousand four hundred and eighty-three cubic meters
iv. The volume of overburden estimated to be removed in the surveyed area is two hundred and seven thousand, three hundred and forty-six cubic meters.
v. It is recommended that the depth below 40m be investigated in the future to determine the occurrence of minable basement rocks.

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