Determination of Porosity and Density of rocks in Kwali Area Council, North-Central Nigeria.

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Abstract: Porosity and density of rocks were determined in Kwali Area Council of the Federal Capital Territory, Nigeria. This study was done towards determining rock samples densities and porosities when wet and dry; ultimately determine their specific gravity and reveals their significance to human race. The methods employed include laboratory method, computational approach which was guided by Archimedes Principle.The result suggests that density and porosity are controlled by fundamental processes that are common to all rocks. And the close correspondence of the measured and lithology porosities and densities therefore indicates that the computational approach adequately handles these textural and mineralogical variations. However, great variations are observed in both density and porosity for a particular identical rock types. Gneiss for example varies in both porosity and density from 15.79% to 36.17% and 2.60g/cm^3 to 2.83g/cm^3 respectively for the four samples of gneiss. The variation in density and porosity for a particular rock type gives an insight on the need of investigating even the same rock types before using them for a particular project, as some rocks have been subjected to greater pressure, temperature and weather conditions than others due to variations in geographical locations. It is apparent from this study to note that there is considerable overlap between different rock types and consequently, identification of a rock type is not possible solely on the basis of porosity and density data.
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1. Introduction

Earth science deals with the study of the earth, its history, changes and its place in the universe. A rock is defined as an aggregate of one or more minerals that have been brought together into cohesive solid (Tillery, 2005). The principal factors controlling the strength of solid rocks are density and porosity (Augustinus, 1991). Density is important in various undertaking in the mining industries; thus Specific gravity is used in the separations of minerals. Architects and Geoscientist used the knowledge of density in the design of bridge, flyovers and other structure (Abott, 1998). The economic evaluation of a petroleum accumulation demands knowledge of the distribution of physical property (porosity) in rocks. The mining of rocks and minerals for their metal ore content has been one of the human advancements, which has progressed at different rates in different places including Nigeria because of the kind of metals available from the rocks of a region (Blatt and Robert, 1996). There is an apparent increase in the collapse of buildings, bridges, flyover, and roads and as well as other structures in both developed and developing countries including Nigeria. The alarming increase in both population and infrastructure development in Kwali Area council has necessitated the need for proper structural planning and development of these infrastructures and building. However, poor planning and inability to carryout pre-developmental geophysical studies and the non-diagnostic property of a particular rock type in construction of building or bridge have led to lot of structural problems which result in dilapidation of building, lost of resources and death during collapse of buildings. The average compositions of rock-forming minerals (Poldervaart, 1955); the diagnostic properties of some common minerals and rocks; the intrinsic properties controlling rock strength, which include density and porosity are important variables used in investigating all the rock forming minerals in the studied area. Therefore, this research work is aimed at;

- Collection of rock samples of true representation,
- Computation of their particle densities and porosities when dry and wet; ultimately determine their specific gravity,
- Relate the measurements to lithological data in order to compare the accuracy and precision of experimental methods, and
- Reveal their significance to human race.

2. Location, Accessibility and Geology

Kwali is one of the major settlements in the Federal Capital Territory. It is located at the intercept of latitudes 8^{0}30' N and 8^{0}55' N and longitudes 6^{0}45' E and 7^{0}05' E of the equator and about 70km away from the federal capital city. The area covers a total of 1,700400 square kilometers or 8,895 hectares, located at the centre of very fertile agricultural area with abundant clay deposits. It is located along Kaduna - Lokoja road. The survey areas are part of the Nigerian basement complex, which occupied mainly hills and dissected terrain (Dawam, 2000). The rock types include schist, gneiss and some older granite. The map in figure1 shows the various locations where the samples were collected.

Physiography and climate

Kwali Area Council is largely drained by River Gurara. The drainage pattern is mainly dendritic and the area is characterized by slightly undulating topography; this shows that the area is generally hilly with most part 70 m above the sea level. The climate of the area under study is tropical with a mean maximum monthly temperature of about 37ºC. The start of rain is from March and end around October (Dawam, 2000). This gives rise to frequent rainfall and a noticeable increase in the mean annual total. The mean annual rainfall is approximately 1038.5 mm. The sunshine of the area ranges between 8 to 10 hours during the period of January to April/May. The annual temperature is between 23.5-38ºC, while the average air pressure of the area is about 1050 millibars.

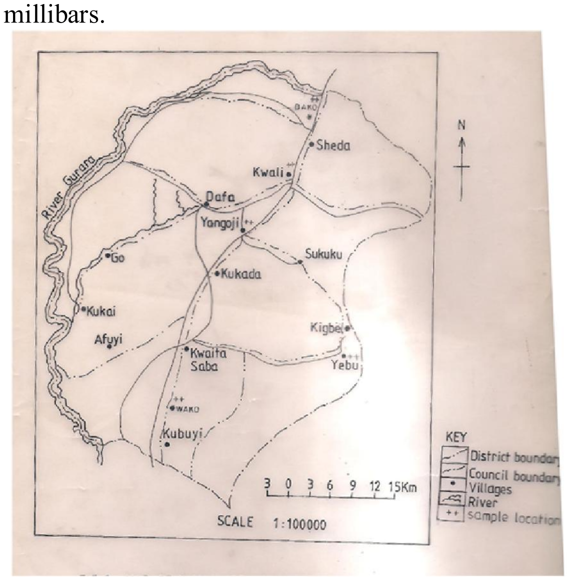

Figure 1: The approximate field location showing the survey areas

3. Materials and Methods

The materials used for this study include spring balance, thread and stand, beaker or cylinder (plastic), bucket, water, rocks sample and graduated cylinder (5000ml). The methodology used involved a laboratory method for the determination of porosity and density of some surface sample of rocks in some selected locations within the area of study. This method was observed on a small sample of rock in a laboratory (Athy, 1930), and was guided by Archimedes principle. Rocks samples were collected from all the locations within the area council so as to obtain a specimen of true representation. After the collection, they were broken into a measurable size and shape, dried properly for six hours so as to remove the moisture contents; before the actual measurement was taken.

Porosity verification was done with the aid of the equation below:

For a rock of matrix volume, V_m the porosity, Φ is derived as follows

$$\Phi = \frac{V_p}{V_b} = \frac{V_b - V_m}{V_b} \quad (1) \text{ (Muller, 1967).}$$

Where

$$V_m = \frac{W_d - W_w}{P_f} \quad (2)$$

$$V_b = \frac{W_s - V_w}{P_f} \quad (3)$$

Putting (2) and (3) into (1) to obtained

$$\Phi = \frac{W_s - W_d}{W_s - W_w} = \frac{W_s - W_d}{W_s - W_w} \times 100\% \quad (4)$$

Where, V_b = bulk volume of rock
V_p = pore space of rock
W_d = dry (air) weight of sample
W_w = wet weight of the sample
W_s = saturated weight of sample
P_f = density of fluid (water)

In the same vein, the relative density also known as specific gravity (SG) of rock was verified with the aid of equation below; Mathematically;

$$\ell = \frac{M_d}{V} \quad (5)$$

$$\text{Specific Gravity} = \frac{W_d}{W_d - W_w} \quad (6)$$

Where,
Weight of rock in air $=W_d$
Loss of weight in water = W_d – Ww.
Density = ℓ

For this experiment, water was used as the fluid ($P_f = 1.0 g/cm^3$).

The dry weight (W_d) of each sample was taken using the spring balance. Followed by respectively taken the reading for the wet weight (W_w) after the sample was been submerged in water. The samples were then soaked for 24 hours (till the samples are allowed to be saturated) in a bucket of water. After which the samples were reweighed as the saturated wet (W_s). The porosity is then computed using the relation given in equation (4). The dry weight (W_d) of each sample was taken using the spring balance. The graduated cylinder was then filled with water to a level that covered the sample completely; the volume of the water was taken as V_1. By means of a thread, each sample was fully submerged in the cylinder containing the water. And the volume was then recorded as V_2. The total volume, V of each sample was obtained by subtracting V_1 from V_2. i.e. $V = V_2 - V_1$. The density was then computed using the relationship given in equation (5). Hence specific gravity (SG) obtained using the relation in equation (6).

4. Results and Discussion

All data presented below have been subjected to careful computational and statistical analysis and have been shown to be highly significant.

Table 1: Density Data Presentation

S/NO	Classes of rock	Rock Type	W_d (N)	W_w (N)	M_d (gm)	V_1 (cm^3)	V_2 (cm^3)	V (cm^3)	Density (gm/cm^3)	S.G
KWALI										
1	Sedimentary	Sandstone	1.05	1.03	105	600	650	50	2.10	52.5
2	Sedimentary	Dolomite	2.62	2.60	262	600	710	110	2.38	131
3	Sedimentary	Halite	1.50	1.45	150	600	670	70	2.14	30
4	Igneous	Glass	1.20	1.17	120	600	650	50	2.40	40
YEBU										
1	Igneous	Granite	0.97	0.80	97	600	638	38	2.55	9
2	Sedimentary	Dolomite	0.70	0.65	70	600	630	30	2.33	14
3	Igneous	Glass	1.25	1.15	125	600	650	50	2.50	12.5
4	Igneous	Basalt	0.95	0.90	95	600	635	35	2.71	19
YANGOJI										
1	Sedimentary	Sandstone	2.00	1.90	200	600	690	90	2.22	20
2	Igneous	Gabbro	1.35	1.26	135	600	645	45	3.00	15
3	Igneous	Glass	0.75	0.65	75	600	630	30	2.50	7.5
4	Metamorphic	Gneiss	1.05	0.95	105	600	640	40	2.63	20
WAKO										
1	Sedimentary	Sandstone	1.25	1.10	125	600	650	50	2.08	8.33
2	Sedimentary	Limestone	1.56	1.42	156	600	660	60	2.60	18.75
3	Sedimentary	Halite	1.70	1.60	170	600	680	80	2.13	17
4	Igneous	Glass	1.00	0.95	100	600	640	40	2.50	20

Table 2: Porosity Data Presentation.

S/NO	Classes of rock	Rock Type	W_d (N)	W_w (N)	Ws (N)	POROSITY
KWALI						
1	Sedimentary	Sandstone	1.05	1.03	1.15	83.33%
2	Sedimentary	Dolomite	2.62	2.60	2.65	60%
3	Sedimentary	Halite	1.50	1.45	1.60	66.67%
4	Igneous	Glass	1.20	1.17	1.25	62.50%
YEBU						
1	Igneous	Grainite	0.97	0.80	1.02	31.82%
2	Sedimentary	Dolomite	0.70	0.65	0.75	50.00%
3	Igneous	Glass	1.25	1.15	1.30	33.33%
4	Igneous	Basalt	0.95	0.90	1.10	75.00%
YANGOJI						
1	Sedimentary	Sandstone	200	1.90	2.30	75.00%
2	Igneous	Gabbro	1.35	1.26	1.40	35.71%
3	Igneous	Glass	0.75	0.65	0.80	33.33%
4	Metamorphic	Gneiss	1.05	0.95	1.15	50.00%
WAKO						
1	Sedimentary	Sandstone	1.25	1.10	1.30	25.00%
2	Sedimentary	Limestone	1.56	1.42	1.82	65.00%
3	Sedimentary	Halite	1.70	1.60	1.60	50.00%
4	Igneous	Glass	1.00	0.95	1.05	50.00%

Table 3: The approximate Lithological porosity for some common rock types (Athy, 1930).

ROCK TYPES	POROSITY (%)
Limestone	7.00 – 56.00
Sandstone	5.00 – 30.00
Dolomite	0.00 – 20.00
Fractured basalt	5.00 – 50.00
Karst limestone	5.00 – 50.00
Shale	0.00 – 10.00
Fractured crystalline rock	0.00 – 10.00
Dense crystalline rock	0.00 – 5.00
Weathered granite	34.00 – 57.00
Weathered gabbro	42.00 – 35.00
Schist	4.00 – 49.00
Quartz	6.00 – 65.00

Table4: The approximate Density ranges for common rock types and ores (Phili et al, 2002).

ROCK TYPES	RANGE OF DENSITY (g/cm^3)
Alluvium (wet)	1.96 – 2.00
Clay	1.63 – 2.60
Shale	2.06 – 2.66
Sandstone	2.05 – 2.55
Limestone	2.60 – 2.80
Chalk	1.94 – 2.23
Dolomite	2.28 – 2.90
Glass	2.40 – 2.80
Halite	2.10 – 2.40
Granite	2.52 – 2.75
Granodiorite	2.67 – 2.79
Anorthosite	2.61 – 2.75
Basalt	2.70 – 3.20
Gabbro	2.85 – 3.12
Gneiss	2.61 – 2.99
Quartzite	2.60 – 2.70
Amphibolites	2.79 – 3.14
Chromite	4.30 – 4.60
Pyrrhotite	4.50 – 4.80
Magnetite	4.90 – 5.20
Pyrite	4.90 – 5.20
Cassiterite	6.80 – 7.10
Galena	7.40 – 7.60

Comparison Of The Results Obtained With The Lithological Data

Lithological data and measured values of density and porosity of rocks are compared using tables 3, 4, 2 and 1. Virtually all the measured values of both density and porosity are within the lithology range given in table 3 and 4. This suggests that density and porosity are controlled by fundamental processes that are common to all rocks. And the close correspondence of the measured and lithology porosities and densities therefore indicates that the computational approach adequately handles these textural and mineralogical variations.

However, great variations are observed in both density and porosity for a particular identical rock types. Gneiss for example varies in both porosity and density from 15.79% to 36.17% and $2.60g/cm^3$ to $2.83g/cm^3$ respectively for the four samples of gneiss. These may be due to three major important reasons:-

i. Measurement errors due to the inherent uncertainties in input and calibration data on the instrument used.
ii. Geometrical variables. Micro scale variation in texture (the grain size and the degree of sorting).

iii. Physicochemical variables are also important. These include temperature, stress, chemistry of the pore water, mineralogy and weathering process.

From review of the written works with artistical value that was carried out by various researchers in different parts of Nigeria proved beyond reasonable doubt that the density and porosity of the rock is an important field of study due to its accessibility of the effects of geographical variations on geophysical parameters. The result gotten by various researchers from different part of the country show some inter-relationship in the value obtained (e.g. comparing the value obtained in Federal Capital Territory and the one obtain from Ondo State, Nigeria) ranging from 2.00g/cm^3 to 3.06g/cm^3 and 2.63g/cm^3 to 2.18g/cm^3 respectively. Both area ranges from 2.00g/cm^3 to 3.06g/cm^3. The researched work shows that the density of rocks determines it's weathering; that is the denser the rock, the higher the weathering rate. This give a clear insight to what is likely to be obtain, when the density is high the rock is slightly prone to weathering and disintegration. So the density of some rock specimens determines its usefulness in construction work.

From the result obtained by Alhassan et al; (2011) that carried out measurements of rocks densities in Gwagwalada area of Federal Capital Territory gives a result in the range of 2.00g/cm^3 to 3.06g/cm^3 which is similar to the present results in this study. This may be because they both have the same geological settings.

Conclusion

Kwali area council from the experimental result is seen to be made up of sedimentary and igneous rocks. Glass is found to be common to all the locations. Dolomite a twin to limestone which is found to be present in all except Wako. It is used for agriculture, chemical and industrial application as well as cement construction. Halite a sedimentary type of rock found in Kwali, Yangoji, and Wako, it is used for food preservation, preparation of sodium hydroxide, soda ash, caustic soda, hydrochloric acid, chlorine and metallic sodium. Gabbro also an igneous rock found only in Yangoji location is also used for all sort of construction and has the highest density 3.00g/cm^3. Gneiss the only metamorphic rock found Yangoji part of Kwali area council. It is used as a building material such as flooring ornamental stones, gravestones, facing stones on building and work surfaces. And finally limestone which is only found in Wako use as aggregate or base for road and foundations, purification of molten glass and also for agriculture and industrial use. The highest porosity values (83.33%) with its correspondence density value (2.10g/cm3) are represented by sandstone. Porosity and pore-system interconnectivity are therefore two very important controls on sandstone reservoir quality as they determine the rock's ability to store and to transmit fluids. The variation in density and porosity for a particular rock type gives an insight on the need of investigating even the same rock types before using them for a particular project, as some rocks have been subjected to greater pressure, temperature and weather conditions than others due to variations in geographical locations. Gneiss, for example has porosities and densities ranging from 15.79% to 36.17% and 2.6g/cm^3 to 2.83g/cm^3 respectively. It is apparent from this study to note that there is considerable overlap between different rock types and consequently, identification of a rock type is not possible solely on the basis of porosity and density data.

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