DETERMINATION OF THE DENSITY OF ROCK SAMPLES FROM BENUE TROUGH IN SOUTH EASTERN NIGERIA

Supported by tetfund

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Received: May 18, 2023 **Accepted:** July 10, 2023

Abstract

The Benue trough in southeastern Nigeria comprises many geologic Formations of different ages. The study area is within latitudes 5°20′N to 6°40′N and longitudes 7°20′E to 8°00′E. It covers towns such as Afikpo, Nkalagu, Awgu and Ohafia. The aim is to establish bulk density of rocks in these locations by determining their specific and relative densities using the laboratory Archimedes principle. A total of 41 samples were collected and analysed. The rock samples include: Nkalagu shale, limestone; Afikpo sandstone, shale, coal, dolerite; Awgu shale, sandstone, ferrugenized sandstone and Ohafia-Arochukwu area sandstone, shale. Results of average densities of rock samples of shale vary from 1.216g/cm^3 to 2.671g/cm^{3}as variation is dependent on age. Ferruginized sandstone in Awgu is 2.4g/cm^{3}and standstone average density is 1.74g/cm^{3}in Awgu, 2.0974g/cm^3 in Afikpo and 2.1474g/cm^3 in Ohafia-Arochukwu axis. The average density of limestone in Nkalagu is 2.7g/cm^3, coal is 1.46 g/cm^{3}and dolerite is 3.22 g/cm^3. The density maps established serve as tools for geological and structural imaging of the area. It is recommended that further studies be carried out to enhance mineral exploration in the area.

Keywords: Bulk Density, Sample, Formations, Relative density, Diorite, Shale, Archimedes Principle

Introduction

Density is the distribution of a quantity of material such as mass, electricity or energy per unit usually of space in the form of length, area or volume, Merriam Webster dictionary (2021). It can be defined in terms of weight per unit volume and expressed as the grammes per cubic centimeter (g/cc or g/cm^3). The symbol is rho,ρ the Greek letter as the representation.

Every material on earth and within the atmosphere that has mass and volume must have its related density. So, density is a very important property and serves as a tool in understanding the type of material it is.

Density of materials varies according to the nature, be it air, liquid or solid. Air is gas and there are various types of gases of which the densities are different likewise liquids and solids, Webster's (2021). Density, ρ is the substance's mass (m) per unit of volume (v). Mathematically expressed as mass divided by volume and the unit is kilogramme per cubic metre

$$Density\ (\rho) = \frac{Mass(m)}{Volume(v)}$$

Specific gravity or relative density is the ratio of the density of a substance to that of standard substance, water = 1g/cm^{3}for example (Encyclopedia Britainica 2023).

Archimedes principle deals with the forces applied to an object by fluids surrounding it. The applied force reduces the net weight of the object in the liquid. By Archimedes law, the buoyant force on the object is equal to the weight of the fluid displaced.

Force = Weight = ρgv (www..geology.iupui.edu/research-bulk/index.htm, Trustees of Indiana University, 2023).

Rocks are solids. Geologic materials formed as solids do so at different conditions of temperature and composition. Hence, density of rocks is condition bound.

The density of rocks is to an extent is a function of the densities of individual grains or minerals, the porosity and the fluid filling the pores, (Olukayode 2012). For specific rock types, density has less percent variability, at specific places due to the low porosity and permeability of igneous and metamorphic rocks, the densities are considered close approximate of the field values (Subrahmanyam and Verma, 1981). Sedimentary rocks are less density than the former.

Rock density determination can be done in one of three ways which include measurement of mass and volume, use of Archimedes Principles, Kairey and Brooks (2006) and use of specific Gravity bottle.

The bureau of Indian standards (Is 13030:1990) recommends three methods of determining the density of rocks. These methods are independent in measurement of bulk volume and dry volume rather than mass (or weight) measurement which can be performed by an electrical balance relatively easily and accurately. These methods are porosity and Density Determination using Saturation and Caliper Techniques. This method of test covers the procedure for determining the porosity and dry density of rock samples in the form of specimen or regular geometry. This is applicable to non-friable coherent rocks that can be machined and do not appreciably swell or disintegrate when that are over dried or are immersed in water.

The second method is porosity and Density Determination using saturation buoyancy techniques. This affects the rocks in lumps or aggregates of irregular shape geometry. Other conditions in method one is applicable.

The third method is porosity and Density Determination Using Mercury Displacement and Grain specific Gravity Techniques. This method of test covers the procedure for determining the porosity and the density of a rock sample in the form of lumps or aggregate of irregular geometry. This is particularly suitable if the rock is liable to swell or disintegrate if immersed in water. The test is also applicable to regularly shaped rock specimens or coherent rock materials but, other techniques are usually found more convenient in these cases.

Archimedes method is used because of availability of equipment and cost effectiveness of materials, though it has its drawbacks and challenges, Ed Vitz et al (2023). The Archimedes method best suites testing less stable rocks such as shale and some sands which cannot withstand prolonged stay in water or heating before disintegrating.

Archimedes method involves using a weighing balance and an instrument called a measuring or volumetric cylinder. The mass is normally measured with an appropriate scale or balance and the volume may be measured directly (from the geometry of the object) or by the displacement of a fluid. For determining the density if a liquid, a hydrometer may be used.

Uses of density data is of immense importance in various aspects of geology, such as isostacy, gravity interpretations, rock and mineral classifications, etc. (Ajakaiye and Broke 1972, Ajakaiye and Sweeney, 1974).

It plays a great role in physical property of geologic materials which aids in identification of rocks and estimation of one abundance, Opara, 2012. It is also related to porosity and permeability and is this valuable in water and hydrocarbon resource exploration and for assessing rock conditions. The densities of rock samples from an area could also be of help in deciphering the geologic history of that area. Density of a substance is of paramount importance in engineering because it is used to differentiate substances. Knowledge of rock density is also important in engineering for design and specification of drilling tools. Then density of a substance is unique to that substance at room temperature and pressure.

Selemo et al (1995) in their work determined the mean bulk densities from Afikpo area. The main bulk density of sandstone ranges from 2.06g/cm^3 to 2.88g/cm^3, the siltstone ranges from 2.3g/cm^3 to 2.88g/cm^3, limestone has a mean bulk density of 3.07g/cm^3 while dolerite has a mean density of 3.19g/cm^3.

Amigun and Ako, (2009) determined using Archimedes principle, the densities of various rocks in Okene area North Central Nigeria. Analysis of the resulting data showed rocks density values in the range of 1.5x10^{3}kg/m^3 to 3.0x10^{3}kg/m^3$\pm$ 0.8 correlated with gneisses while densities greater than 3.0x10^{3}kg/m^3$\pm$0.5 represent iron ore. The rock samples categorized under the iron ore also indicated frequency peaks at density range 3.1x10^{3}kg/m^3 - 3.3 x10^{3}kg/m^3 and 4.2x10^{3}kg/m^3- 4.4 x10^{3}kg/m^3 $\pm$ 0.5 which signifies two Iron ore types i.e magnetite and hematite ore respectively. The comparison of the density map and geologic map of the area showed good correlation which was used to delineate the iron ore deposit from host for possible ore mineral prospecting.

Location, Extent and Accessibility

The study area is in four different locations including: Ohafia- Arochukwu, Nkalagu, Afikpo and Agwu. Ohafia - Arochukwu part lies within 5^0 26′ 23.00″ N to 5^0 29′00″N, and longitudes 7^0 52′ 49.00″E to 7^0 55′ 01″E. It is part of Anambra Basin which is located in the southern part of the regionally extensive Northeast –Southwest trending Benue Trough. Nkalagu lies between the latitude 6^0 27′56.8″N to 6^0 32′ 50.4″N and longitudes 7° 46′ 34.2″E to 7^0 48′ 03.3″E covering the areas around the Nigerian Cement Factory, Nkalagu, the tower line and CNCC Nigeria Limited Construction Quarry. The Afikpo sample spots are located within the Afikpo syncline in the South eastern Nigeria within latitudes 5^0 45′ 5.0″N to 5^0 54′ 30″N and longitudes 7^0 49′ 10″E to 7^0 55′ 55″ E. Afikpo syncline is also traceable or extends to the Cross River Basin of the Benue trough. The place is accessible by roads. Awgu lies within 6^0 01′ 38.5″ N to 6^0 28′ 6.3″ N and Longitudes 7^0 26' 44.3''E to 7^0 28' 38.2"E. It is well accessible through roads with vehicles and foot.

Methodology

A total of 41 sample location were visited and samples collected for analysis from locations such as Nkalagu, NK; Amasiri, AN; Awgu, Ag; Afikpo, As; and Ohafia-Arochukwu Area, OA.

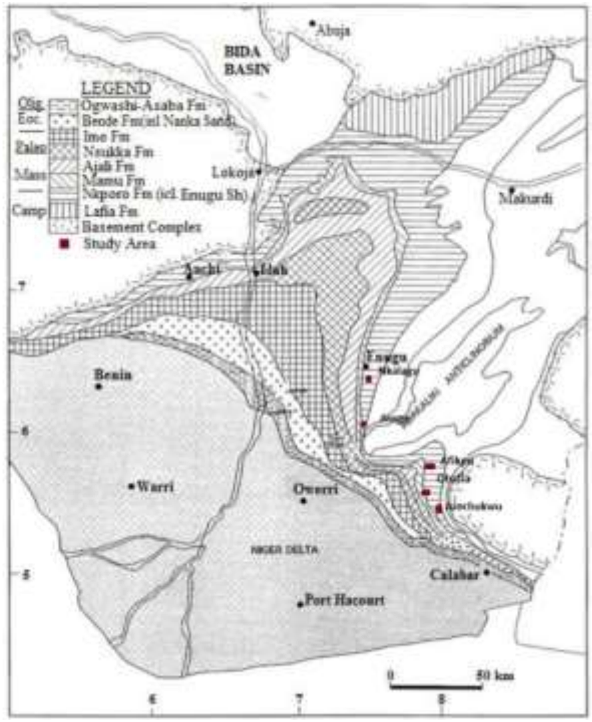

Figure 1: Location of Sample Sites within the Study Area

Materials and Method for Data Acquisition

The materials and instruments used for the study include: Rock samples, Compass, GPS, and Geologic hammer. The field work was carried out and laboratory analyses determined within one week in which the bulk and relative densities of samples were done using the Archimedes method in which a body immersed in a fluid is buoyed up by a force equal to the weight of displaced fluid. Since specific gravity of a rock is a perfect approximation of its density. The conventional method for determining the relative density of granular solids was used to determine the relative densities. The bulk density is computed from

$$\text{Bulk Density} = \text{Specific Gravity x Density of water } (1g/cm3)$$

$$\text{Specific Gravity (SG)} = \frac{\textit{Weight in air } (\text{W1})}{\text{Weight in air W1} - \text{Weight in water (w2)}}$$

Bulk density is the actual density of the particles and the pore spaces. The actual density can be determined by weighing a certain volume of rock sample and drying the grain in the oven or heating it. The samples are weighed in water, air and the difference gives actual density. The weighed samples poured into a graduated cylinder containing enough water to cover the sample and checking the increase in volume. Also, the sample can be attached to a scale and dip into water without the spring scale in the water. The difference in volume is given as the bulk density, since the amount of fluid displaced is equal to the density of the sample.

Results and Discussion

The results of the laboratory tests are presented in the Tables and Figures below: All the samples within these locations are in Ezeaku Formation of Turonian Age. The minimum density of shale is 2.21g/cm^3, maximum value is 2.67 g/cm^3 while the average density is 2.4 g/cm^3. The limestone density ranges from 2.49 g/cm^3 to 2.95 g/cm^3, Figure 2a, 2b and 2c.

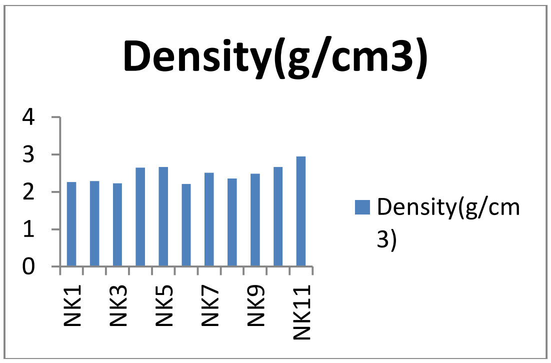

Figure 2a: Shale and Limestone Density values from Nkalagu Area

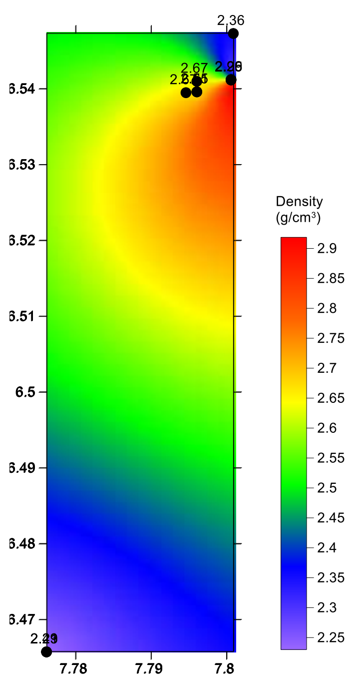

Figure 2b: Image of Shale and Limestone Density values from Nkalagu Area

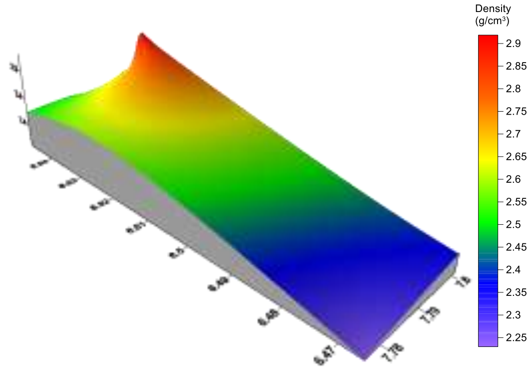

Figure 2c: 3-D Model of Shale and Limestone Density values from Nkalagu Area

All the samples within these locations are in Ezeaku Formation and the age is Turonian except samples AN_{14} and AN_{15} that are Campanian and Maastrichian in age respectively, Figure 3a.. The samples from this area include Sandstone, Dolerite, Coal and Shale. The average density of sandstone is 2.09 g/cm^{3}represented by green colour in Figures 2b and 2c. The dolerite has maximum density of 3.22 g/cm^3 and occupies red zone, coal 1.46 g/cm^3 and Shale 1.22 g/cm^3 are denoted by blue part, Figure 3b and 3c.

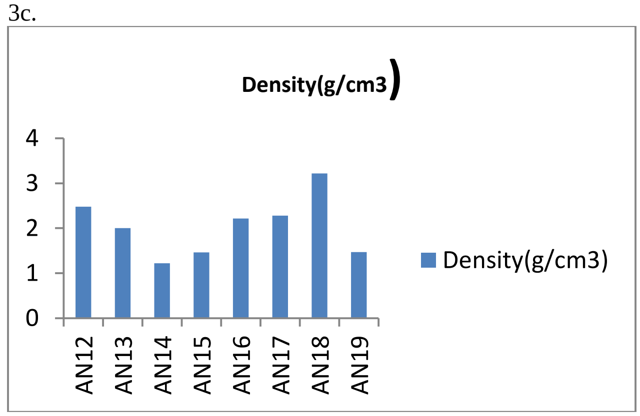

Figure 3a: Sandstone, Shale, Coal and Dolerite Density values from Afikpo North Area

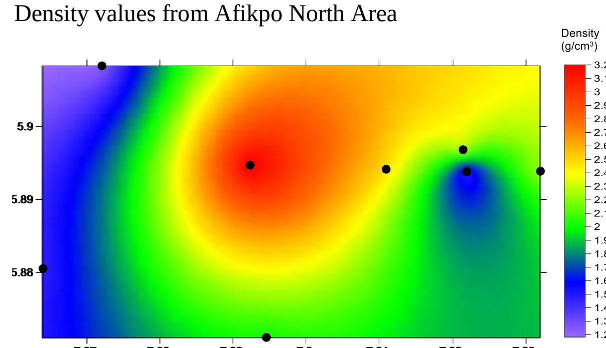

Figure 3b: 2-D Image showing Sandstone, Shale,Coal and Dolerite Density values from Afikpo North Area

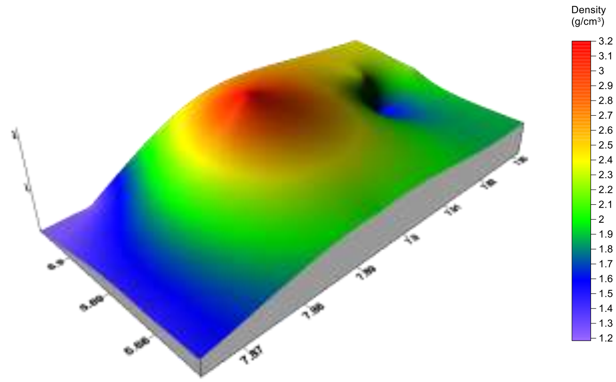

Figure 3c: 3-D Model showing Sandstone, Shale,Coal and Dolerite Density values from Afikpo North Area

AN12, AN13, AN16, AN17, AN18 and AN19 belong to Ezeaku Formation, which is of the Turonian Age. AN14 and AN15 are of Nkporo Formation, Campanian Age and Mamu Formation of Maastritchian Age. AS_{27}, AS_{30}, AS_{31} and AS_{32} are Campanian in age while AS_{28} and AS_{29} are Maastritchian in age.

In Afikpo (ANand AS) area: 14 samples as shown in Figures 3a, 3b, 3cdepicting sandstones with densities 1.47g/cm^3 to 2.48g/cm^3, shale with density of 1.22g/cm^3, coal with density 1.46g/cm^3 and dolerite which represent a major density/gravity anomaly in the area with a density of 3.22g/cm^3. The main density is influenced by different rock densities within this area. The highest rock density say dolerite intrusion and least by Nkalagu shale (1.465g/cm^3) contribute more to this effect. Majority of the rocks collected in this area is shale belonging to Nkporo among other Formations which outcrop there. The determined rock density ranges from 1.40g/cm^3 to 2.26 g/cm^3 with a mean of 1.92g/cm^3, Figure 4. The minimum density value in Afikpo South is 1.4g/cm^3 and the maximum is 2.26 g/cm^3, Figure 4.

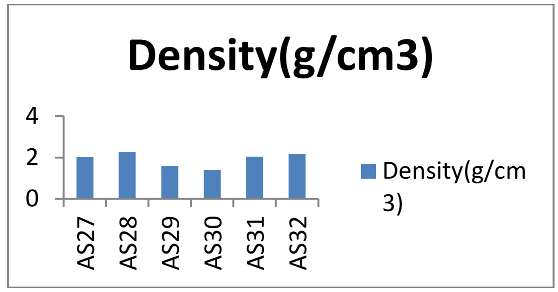

Figure 4: Sandstone, Shale Density values from Afikpo South Area

The data for the two regions combined shows that the area is underlain by rocks of neatly uniform density (shale and sandstones) with a mean of 1.99g/cm^3, and variance of 0.2809. However, a pronounced density maximum occurs to the North at the area corresponding to the dolerite outline. There is slight reduction in the density of rocks to the most of the intrusion and an even more pronounced downward leap to the east. Rock density becomes fairly uniform coming down south from the top of the anomaly, Figure 5. The other pronounced downward plunge far south correspond to area of low density rocks surrounding the intrusion. This could be interpreted as zones of high and low gravity anomalies as seen in the 3-D model, Figure 6.

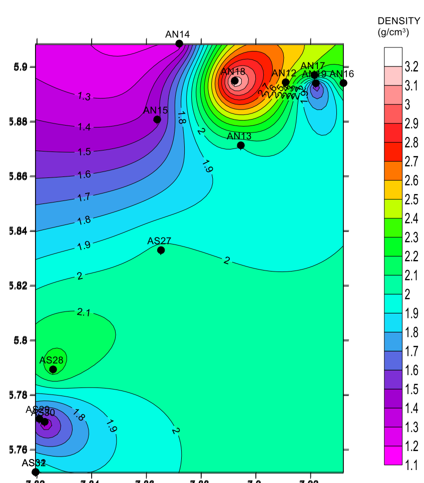

Figure 5: 2D Image/ Contour of sandstone and shale densities within Afikpo North and Afikpo South Area

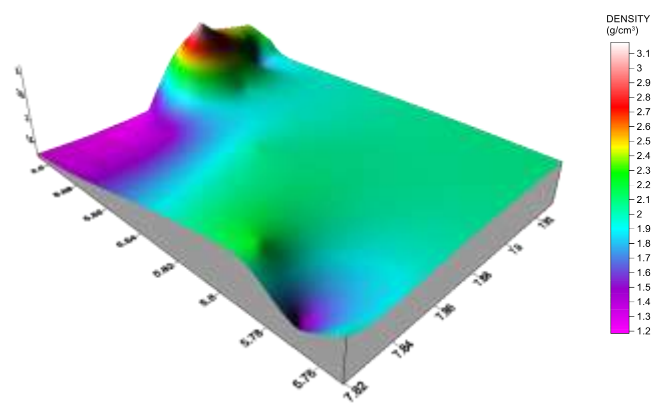

Figure 6: 3-D Model of the sandstone and shale densities in Afikpo North and South Within the study area

In Awgu area, majority of the sandstone outcrops are ferrugenized. The minimum density value of the ferruginized sandstone is 2.14g/cm^3, the maximum value is 2.84 g/cm^3 and the average is 2.49 g/cm^3. Ordinary sandstone density is 1.19g/cm^3, maximum density is 2.06 g/cm^{3}and the average density is 1.74g/cm^3. The density of shale in the area ranges from 1.51 g/cm^3 to 1.64 g/cm^3 with average density of 1.58 g/cm^3, Figures 7 and 8.

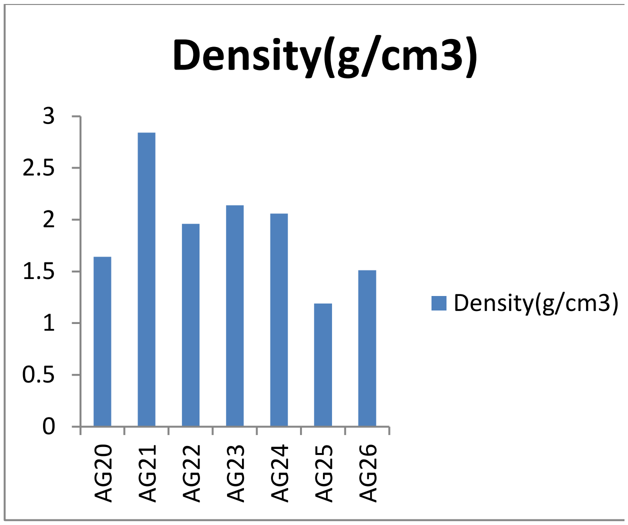

Figure 7: Shale and sandstone Density values of Samples from Awgu Area

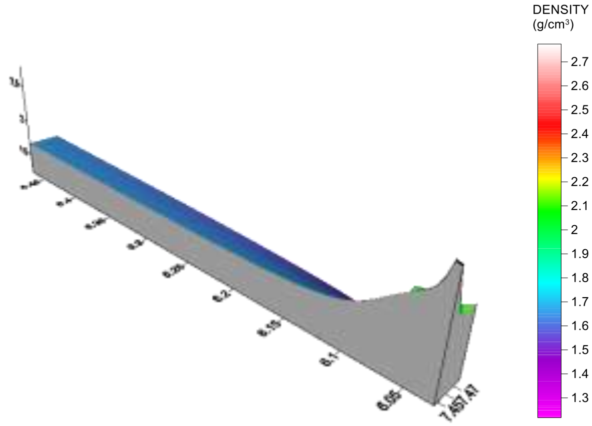

Figure 8: 3-D Model of Shale and sandstone Density values from Awgu Area

The peak of the map corresponds to the location of the ferrogenized sandstone, west of the area underlain by the sands of the low density, Figure 8. The high density ferrogenized sand belong to the Masstruchtian main Formation while the clean sand is of the pre-Masstritchian campanian Nkporo Formation. The model shows a near plane surface for other parts of the area which corresponds to the average rock density of 1.907g/cm^3.

The Ohafia-Arochukwu Axis comprises two major rock samples identifiable as sandstone and shale of the Mamu Formation and Maastritchian in age. The density of shale ranges from 2.14 g/cm^3 to 2.52 g/cm^3 with average density as 2.33 g/cm^3. The sandstone average density is 2.41 g/cm^3 and the range of densities is from 1.86 g/cm^3 to 2.66 g/cm^3, Figure 9.

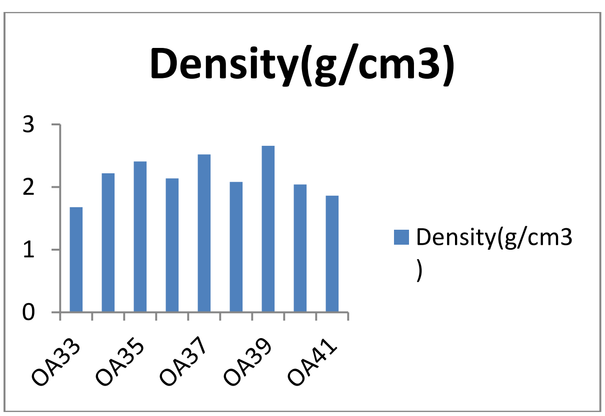

Figure 9: Sandstone, Shale Density values from Ohafia-Arochukwu Area

Figure 9 shows that nine rock samples from the Ohafia-Arochukwu area were analyzed. Seven samples have sandstone lithology while the other two is shale. The density of the sandstone samples are in the range of 1.68g/cm^3 to 2.66g/cm^3 with a mean of 2.14g/cm^3 while the shale have densities of 2.14g/cm^3 to 2.52g/cm^3.

The mean bulk density of all rocks in the area is 2.17g/cm^3 with a variance of 0.098. The low variance implies that the samples are well clustered around the mean, Figure 5 and Figure 6

The densities of shale span a wide range from 1.216g/cm^3 to 2.671/cm^3. Shale of the oldest sampled Formation (Ezeaku) showed a mean bulk density of 3.40g/cm^3 which is higher than that of the younger Nkporo Formation and others. The sandstones of the younger Mamu Formation showed mean bulk density value of 2.19g/cm^3 is higher than those of the older Ezeaku 2.09g/cm^3 and Nkporo 1.80g/cm^3 Formations. This can be said that there is a relationship between rock density and the geologic histories (Locality) as there is no pattern between the density of rocks and their ages.

Conclusion and Recommendations

The bulk density of forty one smples were analysed and their densities determined. The densities of rock samples of shale vary from 1.216g/cm^3 to 2.671g/cm^3 and variation is dependent on age. The average density of shale in Nkalagu area is 2.4g/cm^3, Afikpo North is 1.22 g/cm^3, Awgu 1.58 g/cm^3, Afikpo South 1.92 g/cm^3 and Ohafia- Arochukwu area is 2.33 g/cm^3.

Ferrogenized sandstone occurred mostly in the Awgu with average density of 2.49 g/cm^3.

Sandstone average density varies from 1.74 g/cm^3 in Awgu area, 2.09 g/cm^3 in Afikpo area, and 2.14 g/cm^3 in the Ohafia- Arochukwu area.

Limestone on the surface around Nkalagu has average density of 2.7 g/cm^3. Some limestones are very much denser than shales and sandstones while others were

slightly less dense. Coal has density of 1.46 g/cm^3 and Dolerite is 3.22 g/cm^3.
Sandstone densities changes with mineral composition than age and location. Ferrungenrized sandstones of the younger Mamu Formation have density higher than the pure sandstones of the older Ezeaku and Nkporo Formations.
The densiest rock within the study area is dolerite with density of 3.216g/cm^3 which intruded Ezeaku Formation in Atikpo area.
In conclusion, a density contour map of the area has been created. The resulting density maps serve as tools for geological mapping within southeastern Nigeria. 3-D model of rock density behaviour offers geological and structural imaging of the area. The delineation of limestone deposits and dolerite ridge has been established. The work serves as a reference for future studies and support for gravity data interpretation
It is recommended that further studies be carried out to ascertain the important determinant of a rocks density.

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