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Rock Density of Some Selected Rocks: A case study of some selected rocks in Ado Ekiti Southwestern Nigeria

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ABSTRACT

Rock density is a critical parameter in geological and geophysical investigations, particularly for gravity anomaly interpretation and subsurface characterization. This study determined representative density values for the major lithological units of the Precambrian Basement Complex underlying Ado-Ekiti, Southwestern Nigeria, to provide a reliable density model for geological and geophysical applications. A total of 680 rock samples comprising charnockite, gneiss, quartzite, migmatite, and older granite were collected from representative outcrops and analyzed using the Archimedes principle following oven drying. Statistical analyses were employed to evaluate density distributions and establish mean density values for each lithology. The results revealed mean dry densities of 2.80 g/cm³ for charnockite, 2.70 g/cm³ for gneiss, 2.68 g/cm³ for older granite, and 2.58 g/cm³ for quartzite, with charnockite exhibiting the highest density and quartzite the lowest. Frequency distributions displayed bimodal patterns in several lithologies, reflecting mineralogical and compositional heterogeneity. The overall mean density of the basement rocks was determined as 2.69 g/cm³, representing a characteristic density value for the study area. The established density model provides a robust framework for gravity anomaly interpretation, geological mapping, and subsurface investigations within Ado-Ekiti and comparable Precambrian basement terrains.

Keywords— **Rock density, Basement Complex, Gravity anomaly interpretation, Geophysical prospecting, Precambrian terrain, Ado-Ekiti**

I. INTRODUCTION

Rock density is one of the most fundamental physical properties of geological materials and is widely employed in geological, geophysical, mining, and engineering investigations. Density reflects the mineralogical composition, porosity, degree of weathering, and structural characteristics of rocks, thereby providing valuable insights into subsurface geological conditions. Variations in rock density exert a direct influence on the Earth's gravitational field and constitute the principal source of gravity anomalies measured during geophysical surveys. Consequently, accurate density information is indispensable for geological mapping, crustal studies, mineral exploration, engineering site characterization, and gravity-based subsurface modelling [1], [2].

Gravity methods have become increasingly important in Earth science investigations because of their ability to delineate subsurface density contrasts associated with lithological boundaries, structural discontinuities, intrusive bodies, mineralized zones, and tectonic features. The reliability of gravity anomaly interpretation, however, depends largely on the availability of representative density values for the geological units present within the study area. Inaccurate density assumptions can introduce significant uncertainties into Bouguer corrections, gravity inversion, depth estimation, and geological modelling, ultimately affecting the accuracy of subsurface interpretations [2]. Although a Bouguer reduction density of 2.67 g/cm^3 is commonly adopted in regional gravity surveys, increasing evidence suggests that locally derived density values often provide more realistic geological and geophysical interpretations than generalized continental averages [2], [3].

Recent advances in gravity inversion and density modelling have further emphasized the importance of reliable rock-density databases. [3] demonstrated the effectiveness of integrating gravity data with rock-density measurements to characterize tectonic structures and identify mineralized zones within the Southern Benue Trough, Nigeria. Their findings highlighted the critical role of density information in reducing ambiguities associated with gravity interpretation and enhancing geological understanding of complex terrains. Similar applications have been reported globally in mineral exploration, crustal studies, geothermal investigations, and subsurface characterization, where density contrasts serve as primary constraints for geological modelling and interpretation.

Southwestern Nigeria is underlain predominantly by Precambrian Basement Complex rocks consisting of migmatite–gneiss complexes, quartzites, charnockites, older granites, and associated metamorphic and igneous units. These lithologies exhibit considerable variations in mineralogical composition, texture, metamorphic grade, and structural evolution, resulting in corresponding variations in density. Previous investigations have reported density values for crystalline rocks within different parts of the Nigerian Basement Complex, including the Younger Granite Province [4], the Ilesha–Ifewara schist belt [5], the Ife–Ondo region [6], Akure area [7], and Ado–Ikere Ekiti region [8]. While these studies established important baseline information for gravity interpretation in Nigeria, most were conducted several decades ago using comparatively limited datasets and spatial coverage.

Ado-Ekiti, located within the southwestern Nigerian Basement Complex, comprises predominantly migmatites, gneisses, charnockites, quartzites, and older granites. The heterogeneous nature of these lithological units presents significant density contrasts that are potentially useful for geological and geophysical investigations. Despite the growing application of gravity methods in mineral exploration, geological mapping, and engineering studies within Nigeria, comprehensive and updated density datasets for the major rock units of Ado-Ekiti remain limited. Existing density information is largely derived from historical investigations and may not adequately represent the spatial variability of the lithological units presently exposed within the area.

To address this knowledge gap, the present study evaluates the density characteristics of the major basement rock units within Ado-Ekiti using an extensive dataset comprising 680 representative rock samples collected across the metropolis. The study establishes updated dry and saturated density values, examines their statistical distributions, and compares the results with previously reported density data from other basement terrains in Nigeria. The resulting density database is expected to provide improved constraints for gravity anomaly interpretation, geological mapping, engineering geological assessments, and mineral exploration within Ado-Ekiti and comparable Precambrian basement environments. Specifically, the objectives of this study are to determine the dry and saturated densities of major basement rock units within Ado-Ekiti, establish representative mean density values for the principal lithological units in the study area, evaluate the statistical and frequency distribution characteristics of the density data, compare the obtained density values with those reported from other Nigerian basement complex terrains, and provide a reliable average density model for gravity anomaly interpretation and related geophysical investigations within Ado-Ekiti and adjoining areas. The findings of this study contribute to the development of a modern density database for the Nigerian Basement Complex and provide valuable geophysical parameters for gravity modelling, subsurface characterization, geological mapping, engineering investigations, and mineral-resource assessment.

II. MATERIALS AND METHODS

A. Field Sampling

A systematic field sampling approach was adopted to obtain representative rock specimens from the major lithological units within Ado-Ekiti, southwestern Nigeria. A total of 680 fresh and weathering-free rock samples were collected from natural outcrops, road cuts, quarry exposures, and inselberg surfaces across the study area. Sampling was designed to ensure adequate spatial coverage and lithological representation of migmatites, gneisses, older granites, charnockites, and quartzites. Tables 1 and 2 present samples classifications and designations.Fresh samples were selected based on minimal weathering, absence of fractures, and visible preservation of primary mineralogical textures to reduce bias in density estimation. Each sample was assigned a unique identification code corresponding to its sampling location and lithological classification.

Table 1: Samples Classification

S/N	ROCK TYPE	NUMBER OF SAMPLES
1	Older Granite	300
2	Charnockite	100
3	Gneiss/Migmatite	230
4	Quartzite	50
	Total	680

Table 2: Summary of Sample Numbers and Rock Type

S/N	SAMPLE NO	ROCK TYPE	NO FROM EACH	LOCATION
1	A1 – A40	Granite	40	Piccolo Old Quarry Site
2	A41 – 480	Migmatities	40	Iyin Road, Ado-Ekiti
3	B1 –B30	Granite	30	New Quarry, Ado-Ekiti
4	B31 – B60	Granite	30	Yinka Quarry, Ado-Ekiti
5	C1 – C30	Granite	30	Ori-Apata, Ado-Ekiti
6	D1 – D30	Granite	30	Onigari, Ado-Ekiti
7	D31 – D50	Granite	20	Satellite Campus, Ilawe Road
8	D51 – D60	Granite	10	Vein in location no. 7
9	D61 – D90	Quartzite	30	Mary Immacualte, Ado-Ekiti
10	E1 –E30	Granite	30	Stadium Road, Ado-Ekiti
11	E31 – E50	Granite	20	Adebayo Road, Basiri
12	F1 – F20	Granite	20	Vein in location No. 11
13	F21 – F40	Quartzite	20	Vein in location No. 11
14	G1 – G40	Gneiss	40	Olokemeji, Ado-Ekiti
15	G41 – G60	Charnockite	20	Olokemeji, Ado-Ekiti
16	H1 – H20	Gneiss	20	Odo-Ado, Ado-Ekiti
17	H21 – H40	Charnockite	20	Idemo, Ado-Ekiti
18	H41 – H60	Charnockite	20	Water Works, Ado-Ekiti
19	I1 – I20	Charnockite	20	Water Works, Ado-Ekiti
20	I21 – I40	Charnockite	20	Omolayo Press, Ado-Ekiti
21	J1 – J20	Charnockite	20	Omolayo Press, Ado-Ekiti
22	J21 – J40	Charnockite	20	Agric Road, Ado-Ekiti
23	L1 – L40	Charnockite	20	Agric Road, Ado-Ekiti
24	K21 – K40	Charnockite	20	Bawa Road, Ado-Ekiti
25	M	Charnockite		Secretariat Road, Ado-Ekiti
26	N_1-N_{10}	Charnockite	10	Moferere Area, Ado-Ekiti
27	P1 – P40	Granite	40	Back of Oloyede Hotel
TOTAL			**680**	

Each lithological unit was sampled proportionally to its areal distribution, with higher sample density in heterogeneous zones such as migmatite–gneiss complexes. Geographic coordinates of sampling locations were recorded using a handheld GPS receiver to support spatial referencing and future geostatistical analysis. Sample coordinates and field descriptions were recorded during collection. The large sample size adopted in this study significantly improves the statistical reliability of the resulting density estimates when compared with several previous density studies conducted in Southwestern Nigeria.

B. Sample Preparation

Collected rock samples were cleaned, labelled, and transported to the laboratory for analysis. Each specimen was trimmed into regular or semi-regular shapes to minimize measurement errors associated with irregular geometries. Samples were then oven-dried at 100°C for a minimum of 24–25 hours to remove pore water and ensure attainment of true dry mass conditions. After drying, samples were cooled in a desiccator to prevent moisture reabsorption prior to measurement.

C. Density Determination Using Archimedes Principle

Rock densities were determined using the Archimedes principle based on the relationship between mass, volume, and buoyancy. The dry density (ρ_d) was obtained by measuring the dry mass of each sample in air and its displaced volume when submerged in water. The governing equation is expressed as:

$$\rho = \frac{M}{V} \qquad (1)$$

where: ρ = density of the rock (g/cm³)

M = mass of the rock (g)

V = volume of the rock (cm³)

For submerged measurements, volume was determined using:

$$V = \frac{M_{air} - M_{water}}{\rho_{water}} \qquad (2)$$

where: M_{air} = mass of sample in air

M_{water} = apparent mass of sample in water

ρ_{water} = density of water (assumed as 1.0 g/cm³ at laboratory conditions)

Saturated density values were also computed by allowing samples to reach full water saturation prior to weighing. This enabled evaluation of density variations under different pore-fluid conditions.

D. Laboratory Procedures and Instrumentation

Mass measurements were conducted using a calibrated digital electronic balance with an accuracy of ±0.01 g. Water immersion measurements were performed in a temperature-controlled container to minimize density fluctuations of water. All instruments were calibrated prior to use following standard laboratory quality assurance procedures. To ensure repeatability, each sample was measured at least three times, and the average value was used for final density computation. Outlier values caused by air bubbles, incomplete submersion, or weighing instability were discarded.

E. Data Analysis

Statistical analysis was performed using descriptive statistics including mean, range, standard deviation, and frequency distribution analysis. Histograms were generated for each lithological unit to evaluate density variability and distribution patterns (normal, skewed, or bimodal trends). Mean density values were computed for each rock type and for the overall dataset to establish a representative density model for the study area. The overall mean density ($\bar{\rho}$) was calculated as:

$$p' = \frac{\sum \rho_i}{n} \qquad (3)$$

where: ρ_i = individual sample density

n = number of samples

F. Uncertainty and Error Control

Potential sources of error included instrumental precision limits, air bubble adherence during water immersion, irregular sample geometry, and temperature variation affecting water density. To minimize these uncertainties, strict procedural controls were implemented, including degassing of samples prior to immersion, repeated measurements, and calibration of equipment. Overall measurement uncertainty was estimated to be within ±1.5%, which is acceptable for geophysical density studies and gravity modelling applications.

G. Quality Assurance and Reliability

Quality control measures included duplicate measurements, cross-validation of lithological classification through field petrography, and consistency checks across lithological groups. Only samples with consistent repeated measurements were included in the final dataset. This ensured the reliability of derived density values for geophysical interpretation. The methodological framework adopted in this study aligns with standard practices in rock density determination used in gravity and geophysical investigations, ensuring comparability with previous regional studies and global datasets.

III. RESULTS AND DISCUSSION

A. Density Characteristics of Lithological Units

Table 3 presents the results of density of all the samples. The analysis of 680 rock samples from Ado-Ekiti reveals distinct variations in density across the major lithological units of the Precambrian Basement Complex. The mean dry density values obtained are 2.80 g/cm³ for charnockites, 2.70 g/cm³ for gneisses, 2.68 g/cm³ for older granites, and 2.58 g/cm³ for quartzites. Migmatitic units exhibit intermediate and locally variable densities depending on the relative proportions of felsic and mafic constituents. Among all lithologies, charnockites consistently exhibit the highest density values, while quartzites show the lowest (Figure 1). The overall mean density of basement rocks in the study area is 2.69 g/cm³, which is close to the conventional Bouguer reduction density of 2.67 g/cm³ commonly applied in gravity surveys.

B. Density Distribution Patterns of the Major Lithological Units

Figures 2 and 3 presents the distribution of mean densities in Gneiss. The density histograms reveal significant petrophysical variations among the major lithological units of the Ado-Ekiti Basement Complex. Gneisses and older granites exhibit relatively broad and bimodal density distributions, indicating compositional heterogeneity arising from variations in mineralogy, metamorphic history, and proportions of ferromagnesian minerals [9], [10]. The bimodal patterns suggest the presence of distinct density sub-populations within these lithologies.

Charnockites display the highest density values and a pronounced bimodal distribution, reflecting variations in orthopyroxene and other mafic mineral contents (Figure 4). Their elevated densities are consistent with their mafic-rich composition and explain their potential to generate positive gravity anomalies relative to surrounding felsic rocks [11], [1]. In contrast, quartzites exhibit a narrow and more uniform density distribution, attributable to their predominantly quartz-rich composition and limited mineralogical variability (Figure 5). The relatively low density values and restricted spread indicate a more homogeneous lithology compared to the other rock units [12], [10].

Table 3: Comparative Analysis with Traditional Methods

Metric	Two-Wheel Tiller	Animal Traction	Manual Hoe
Field Capacity (ha/h)	0.04–0.06	0.025–0.04	0.01–0.02
Labour Requirement	1 operator	2 operators + animal	3–4 operators
Fuel/Cost Efficiency	₦500/ha (fuel)	₦1,200/ha (feed)	₦2,000/ha (labour)

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Overall, the observed density distributions demonstrate that mineralogical composition and lithological heterogeneity are the primary controls on density variation within the study area. The occurrence of bimodal density patterns in gneisses, older granites, and charnockites highlights the importance of employing lithology-specific density parameters for gravity modelling and subsurface geological interpretation [2], [1].

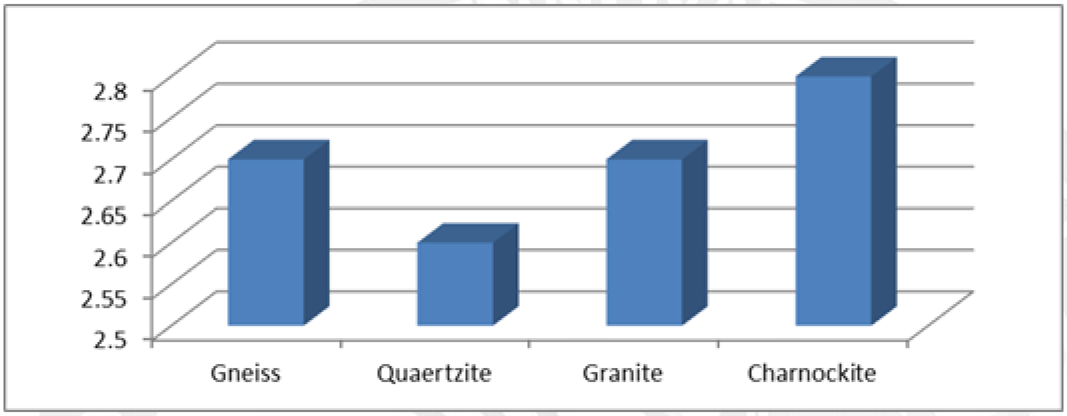

Figure 1 – Histogram Showing the Mean Densities of the Rocks in Ado-Ekiti

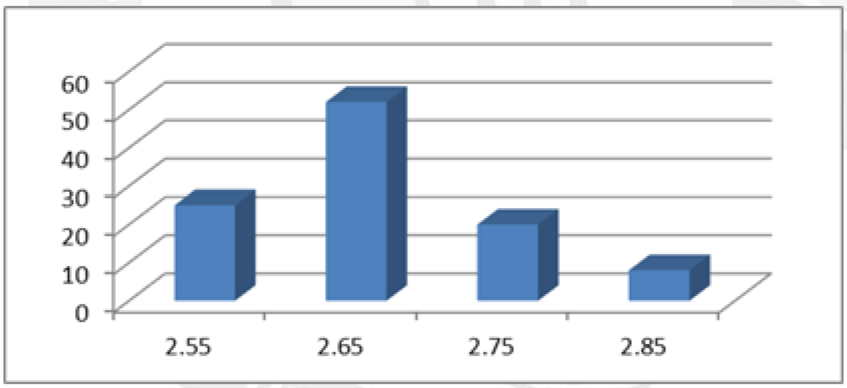

Figure 2 – Histogram showing the Distribution of Mean Densities in GneissMetropolis

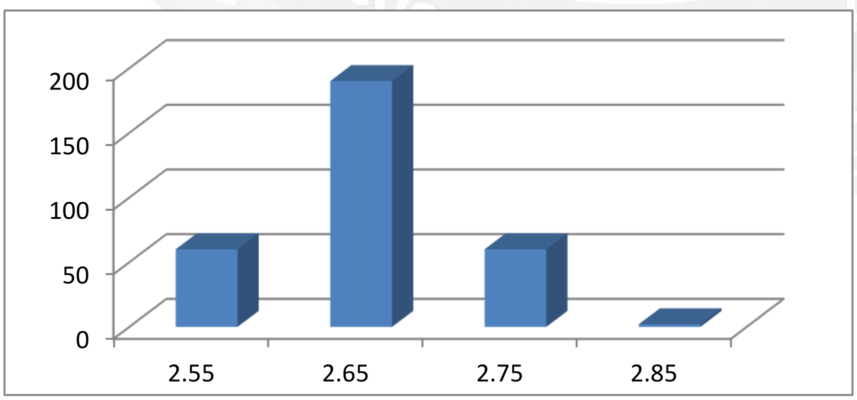

Figure 3 – Histogram showing the Distribution of Mean Densitites in Older Granite

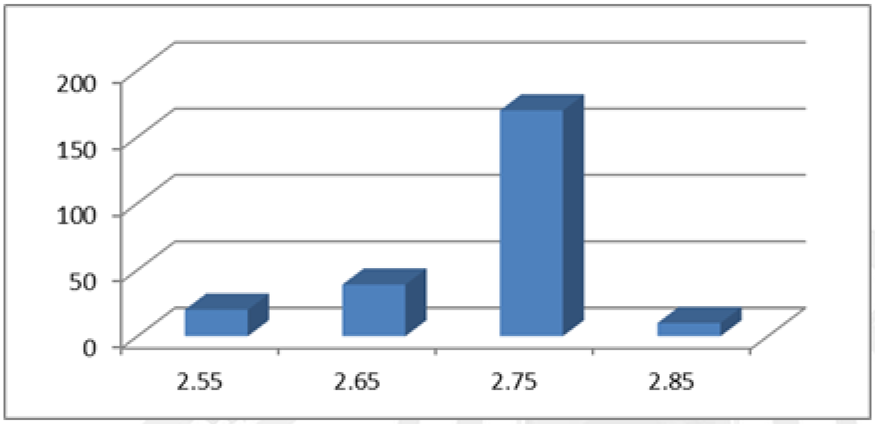

Figure 4 – Histogram showing the Distribution of Mean Densities in Charnockite

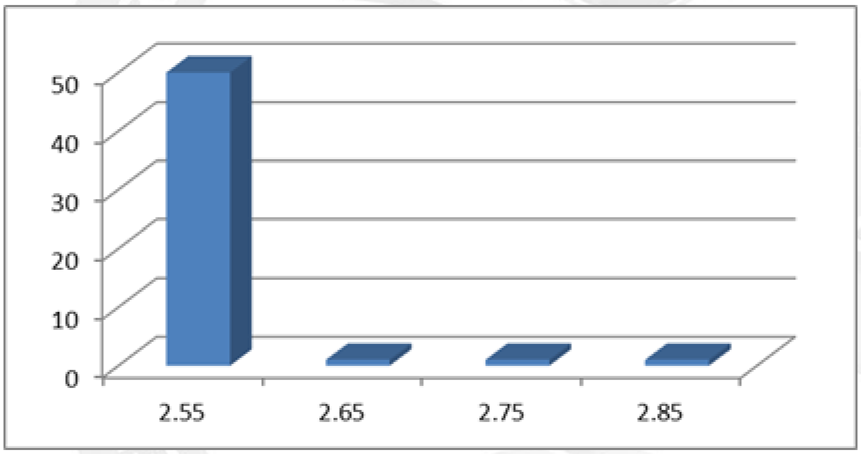

Figure 5 – Histogram showing the Distribution of Mean Densities in Quartzite

C. Lithological Control on Density Variation

The observed density variations are strongly controlled by mineralogical composition, texture, and metamorphic grade. Charnockites show elevated densities due to the presence of orthopyroxene and other ferromagnesian minerals, which increase overall mass per unit volume. This supports their known geophysical signature as high-density lithologies capable of generating positive gravity anomalies in crystalline terrains. Gneisses and older granites exhibit moderate density values, reflecting their mixed mineral composition of quartz, feldspar, biotite, and hornblende. Variability within these units is attributed to changes in mafic mineral content and degree of deformation. Quartzites, being composed predominantly of recrystallized quartz, exhibit the lowest densities due to their mineralogical purity and relatively low mafic content. These results are consistent with established petrophysical principles that relate density to mineralogical composition and metamorphic evolution in crystalline basement rocks [1].

D. Frequency Distribution and Lithological Heterogeneity

The frequency distribution of all the samples are presented in Table 4a, b, c and d. Frequency distribution analysis reveals that several lithological units, particularly gneisses, older granites, and charnockites, exhibit bimodal or multimodal distributions. This suggests significant internal heterogeneity within these rock groups, likely resulting from variations in mineral proportions, deformation intensity, and localized metamorphic processes. The presence of bimodal distributions indicates that these lithologies cannot be treated as uniform density bodies in geophysical modelling. Instead, they should be represented as composite units with variable density ranges to improve the accuracy of gravity inversion and subsurface interpretation. Quartzites, by contrast, show a more narrowly distributed density range, reflecting their relatively homogeneous quartz-dominated composition.

E. Comparison with Previous Studies

Table 5 compares the mean density of Precambrian rocks in Nigeria Obtained by Different researchers. The density values obtained in this study are broadly consistent with earlier investigations conducted within the Nigerian Basement Complex. Studies by [4], [5], [6], and [7] reported similar density ranges for crystalline basement rocks across southwestern Nigeria.

However, slight variations exist due to differences in sampling density, analytical techniques, and spatial coverage. The present study improves upon earlier works by employing a significantly larger dataset (n = 680) and a broader spatial distribution across Ado-Ekiti, thereby providing more statistically robust and representative density estimates. Furthermore, the overall mean density of 2.69 g/cm³ obtained in this study closely aligns with the standard Bouguer correction density of 2.67 g/cm³, although local deviations highlight the importance of site-specific density determination for precise gravity modelling.

Table 4: Frequency distribution of the samples

a. Gneiss and migmattiites

Class limit	**Class boundary**	**Frequency**	**% frequency**
2.55 – 2.62	2. 545 – 2.645	22	22
2.65 – 2.74	2.645 – 2.745	54	54
2.75 -2.84	2.745 – 2.845	18	18
2.85 – 2.94	2.845 – 2.945	06	06

b. Older Granite

Class limit	**Class boundary**	**Frequency**	**% frequency**
2.55 – 2.62	2. 545 – 2.645	57	19
2.65 – 2.74	2.645 – 2.745	186	62
2.75 -2.84	2.745 – 2.845	57	19
2.85 – 2.94	2.845 – 2.945	-	-

c. Charnockite

Class limit	**Class boundary**	**Frequency**	**% frequency**
2.55 – 2.62	2. 545 – 2.645	21	9.13
2.65 – 2.74	2.645 – 2.745	36	15.65
2.75 -2.84	2.745 – 2.845	164	71.30
2.85 – 2.94	2.845 – 2.945	09	3.91

d. Quartzite

Class limit	**Class boundary**	**Frequency**	**% frequency**
2.55 – 2.62	2. 545 – 2.645	50	100
2.65 – 2.74	2.645 – 2.745	-	-
-.		-	-
-		-	-

TABLE 5: Comparism of Mean Density of Precambrian Rocks in Nigeria Obtained by Different Researchers

	Akure Area			**Nigeria younger granite**			**Ilesha-Ifewara [5]**			**Ado-Ekiti metro polis [7]**		
Rock types	**N**	**R**		**N**	**R**	--	**N**	R		**N**	**B**	
Gneiss	**37**	**2.59-2.89**	2.71	**177**	**2.53-2.83**	2.70	**20**	2.60-2.80	2.60	**100**	**2.55-2.94**	2.70
Older granite	**39**	**2.56-2.81**	2.68	**76**	**2.57-2.81**	2.66	**16**	2.58-2.82	2.66	**300**	**2.55-2.94**	2.68
Charnockite	**25**	**2.69-2.97**	2.84	**-**	**-**	-	**-**	-	-	**230**	**2.55-2.94**	2.80
Quartzite	**07**	**2.40-2.65**	2.56	**-**	**-**	-	**20**	2.58-2.67	2.64	**50**	**2.55-2.94**	2.58

Legend:-N = No of samples, R = Range of densities, -. Mean density obtained gcm^{-3}

F. Geophysical and Gravity Interpretation Implications

The results have important implications for gravity-based geophysical interpretation in the study area. The relatively high density of charnockites suggests that they are likely to produce positive gravity anomalies relative to surrounding quartzite-rich and felsic units. Conversely, quartzites are expected to generate localized gravity lows due to their lower density. The moderate density contrast between gneisses, migmatites, and older granites implies that subtle gravity variations in the area may be attributed to compositional differences, structural discontinuities, or variations in metamorphic grade rather than large-scale lithological boundaries alone.

The identified density contrasts enhance the interpretability of gravity data for subsurface modelling, including depth estimation, basement relief mapping, and structural delineation. This is particularly relevant in Ado-Ekiti, where complex deformation and intrusive relationships produce highly heterogeneous crustal architecture.

G. Regional and Global Context

When compared with other Precambrian terrains globally, the density range observed in Ado-Ekiti (2.58–2.80 g/cm³) falls within typical values reported for high-grade metamorphic and granitic basement complexes. Similar ranges have been documented in African cratonic terrains and other Pan-African mobile belts, confirming the geologically expected nature of the results. The consistency of these findings with global datasets reinforces the reliability of the derived density model and supports its application in both regional and comparative geophysical studies.

I. CONCLUSION

This study established an updated rock density database for the major lithological units of the Ado-Ekiti Basement Complex based on 680 representative rock samples. The results indicate that density variations are primarily controlled by mineralogical composition and lithological heterogeneity. Mean dry density values of 2.80 g/cm³, 2.70 g/cm³, 2.68 g/cm³, and 2.58 g/cm³ were obtained for charnockites, gneisses, older granites, and quartzites, respectively, yielding an overall average density of 2.69 g/cm³ for the study area. Charnockites exhibited the highest densities due to their ferromagnesian mineral enrichment, whereas quartzites recorded the lowest values because of their quartz-dominated composition. The occurrence of bimodal density distributions in several lithologies reflects compositional variability and complex petrogenetic evolution. The derived average density closely approximates the conventional

Bouguer reduction density (2.67 g/cm³) but highlights the importance of locally constrained density values for improved gravity modelling and subsurface interpretation. Consequently, the study provides a robust petrophysical framework for gravity anomaly analysis, geological mapping, and geophysical investigations within Ado-Ekiti and similar Precambrian basement terrains.

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