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Prediction of gravity anomaly from calculated densities of rocks

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ABSTRACT

Density and density contrasts of rocks controls gravity anomalies and is an important physical property of geologic material which aids in the identification of rocks, estimation of ore abundances, and assessing rock conditions. The study was carried out with the aim of modeling gravity anomaly from calculated densities. Dry density of twenty five (25) rock samples collected randomly during the geological mapping exercise were analyzed in the laboratory using traditional dry and wet method. The particle density was estimated using the relationship (m2 - m1) / (m4-m1) - (m3-m2). Rocks identified in the area include Granite (av. ρ ~2.72 gm^{-3}), Biotite granite (av. ρ ~2.7213gm^{-3}), and Pegmatite (av. ρ ~ 2.7125 gm^{-3}). Anomaly types described along selected gravity profiles include S, M, Concave up, UL, Zig-Zag Flat top and Stair case anomalies. The 3D modeled gravity anomaly map of the upper part of the study area shows that peaks in the map correspond to the location of the pegmatite outcrop. Along the profiles the pegmatite outcrop are shown as concave up anomalies. Gravity anomalies in the study area are associated with mineralization and ambiguity in the anomalies calculated result from variation in the porosity of the different rock samples.

Keywords: Density, Gravity, Anomaly, Pegmatite, Mineralization

INTRODUCTION

Gravity anomalies result from the difference in density, or density contrast, between a body of rock and its surroundings. Gravity data are used to constrain subsurface density variations associated with tectonics and mineralization. The force of gravity at the earth surface is affected by lateral changes of density due to the total mass of the earth. Two components of gravity forces are measured at the earth's surface, a general and relatively uniform component due to the total earth and a smaller size which varies due to lateral density changes. The latter generally referred to as gravity anomaly is the difference between the observed earth's gravity and a value predicted from a model (Fricke & Schön 1999, Rider 1996, Serra 1984).

The density of a rock is the ratio of its mass per volume. For specific rock types, density has less percent variability especially 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). Unconsolidated materials such as alluvium and stream channels materials may have significant variation in density, due to compaction and cementation. The influence of porosity on density in hard rocks is usually less than one per cent (Henkel, 1976); low density values from igneous rocks may be due to the weathering (Ranganai, 1995) of such rocks.

Direct knowledge of density has been used to predict gravity anomalies without any need for time, elevation, instrument drift, and other gravity corrections especially in basement complex environment. When accurately calculated, densities of rock is essential in petrological and geological studies and more so for a meaningful structural interpretation of gravity anomalies (Ajakaiye & Burke 1972, Ajakaiye & Sweeney, 1974).

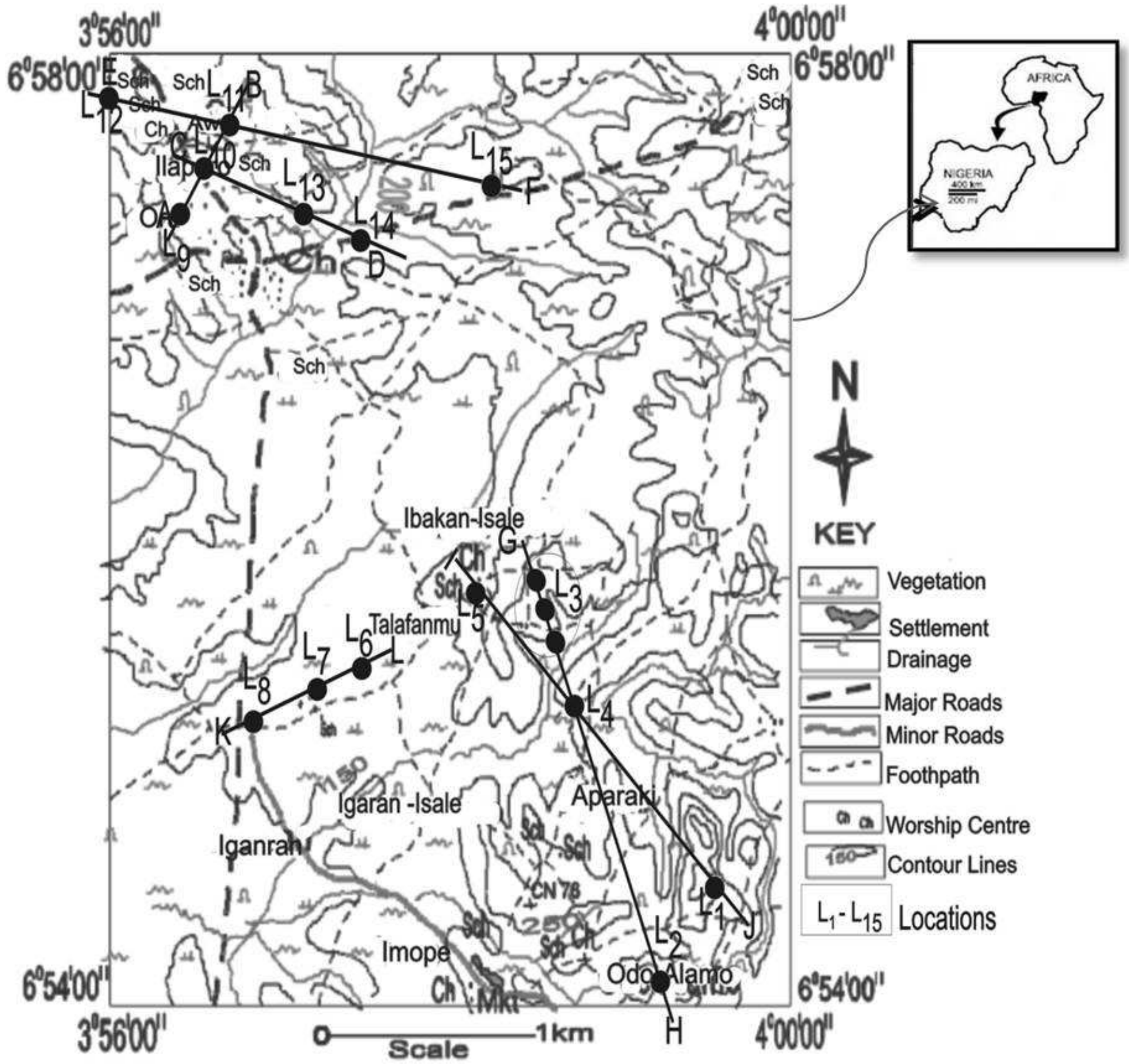

Fig.1: Index map of the study area, accessibility to outcrop is enhanced by major roads and footpaths. Climate is tropical with a sub-dendrite like drainage pattern.

The thrust of this research is to calculate densities of rock samples in the laboratory with a view to predicting gravity anomalies and elucidating the geometry of the pegmatite intrusion in the study area especially as it relates to its representation on the geological map as tabular or elliptical bodies. This work starts by discussing the geology of the area based on the result of the geological mapping exercise, the methods used for the study and the implications of the result.

Local Setting

The study area, is located with longitude E 3^0 56^I - E 4^0 00^I and latitude N $6^0 54^I$ - N 6^0 58^I covering settlements such as Awa, Ilaporu, Oru, Ibakan-Isale , Talafanmu, Iganran, Iganran-Isale, Aparaki, Imope, and Odo-alamo respectively. The study area fall within the tropical rain forest region of Nigeria with most of the parts covered by vegetation. Temperature ranges from 25^oC to 32^oC (Akintola, 1986) alternating wet and dry seasons with maximum rainfall of ~1500mm. The topography is wavy or undulating; with the drainage systems flowing NE-SW direction in sub-dendrite like manner.

MATERIALS AND METHODS

Initial field mapping exercise involved the observation of rocks at outcrop locations, determination of positions using the Garmin GPS in longlat coordinate system, description of mineralogical composition, texture, degree of weathering of rock and collection of twenty four (24) fresh samples for further laboratory studies.

In the laboratory, the samples were heated in an oven kept at a temperature 100^0c for 24 hours under reduced pressure in order to remove all water content and were weighed in air (Mass of Pycnometer + rock particles + water (m^3) and quickly in water(Mass of Pycnometer + rock particles (m^2) using a Mettler balance. All samples were then saturated in water at reduced pressure for 24 hours, weighed again in water (Mass of Pycnometer full of water (m^4) and in air (Mass of Pycnometer (m^1). From the result obtained, the particle density was estimated from the relationship (m^2 - m^1) / (m^4-m^1) - (m^3-m^2). For the density measurements the following parameters were determined for each of the samples: pore volume, bulk volume, or grain volume and weight. Statistical analysis of the data included determination of mean, mode, median and standard deviation.

The 3D gravity anomaly map was computed by plotting estimated density contrast against spatial position on Surfer 8. Longitude and latitudes coordinates were converted into XY (UTM), loaded onto a spreadsheet and the map was gridded using the density values as the z-factor, elevation map of the area was also plotted. The anomaly map was divided into two based on the position of the outcrops in order to avoid overestimation of the density contrasts over locations where rocks are not outcropping. Cross sections were also drawn along selected profiles to further elucidate the gravity anomaly.

In estimating the gravity anomaly, a contrast of <0.2 g/cm^3 was calculated between the granitic rocks and the continental crust which coincides with the temperature less than the granite solidus at depth of <20km (Rast, 1970, Ajakaiye, 1974).

RESULTS AND DISCUSSION

Geology of the study area

The general geology of Nigeria have been previously studied by Rahaman (1971), Oyawoye (1972), Cooray (1972), Elueze (1981), Caby et al (1981), Dada et. al. (1995), Dada (1998), and more recently Omada & Olorunfemi, 2012, Oden & Igonor, 2012, Ekwere & Edet, 2012, Bassey, 2012. The crystalline rocks in Nigeria are distributed in a circular area in the North central, a triangular area in the West which runs into the Benin Republic and a rectangular area broken into three parts by sedimentary rocks on the Eastern border of Nigeria with Cameroun Republic. The Precambrian rocks of Nigeria, collectively known as the basement complex occupy nearly half the total area of the country, and the other half is covered by the Cretaceous and younger sedimentary rocks

The rocks of the study area include Biotite Granite, Granite and Pegmatite (fig.2). There is preponderance of Biotite Granite from North to South, leucocratic rocks characterized by Felsic minerals that generally trend NNW-SSW. The Granites are emplaced on the Eastern and NW margin of the study area where they are flanked by Pegmatite intrusions. The rocks are thought to belong to the older Granite suites (Falconer, 1911) of the Precambrian Basement complex of Nigeria. This rock suite are generally calc alkaline, orogenic rocks of Pan African age (±500ma) and include such rocks as granite, Granodiorite, Adamellite, Quartz, Monzonite, Syenite, and pegmatites.

The granites of the study area are main phase granite bearing dominant minerals such as hornblende and biotite. Other minerals identified in the granites include quartz, k-feldspar and muscovite in subordinate amount to the biotite and hornblende; the rocks generally are phaneritic in texture. The pegmatite occurs both as outcrop and intrusions in other rock types. The minerals are of large grain and coarse texture with; mineralogical compositions include muscovite, tourmaline, quartz and sometimes with dark minerals such as biotite.

Densities

The highest density values was recorded in the biotite granite (~2.75g/cc) while the minimum value was estimated in the Granite (~2.69g/cc) (Table 1,2 & Fig. 3). Average density in the three rock types of the study area are 2.713, 2.72 and 2.721 for Pegmatite, Granite and Biotite granite respectively.

The highest porosity (Φ) value of 8.8% was calculated in the Granite. Coefficient of regression shows that there is low correlation between porosity and estimated density. Covariation of 2% (Fig.5i), 11% (Fig 5ii) and 14% (Fig5.iii) correspond to r value of 0.17, 0.33 and 0.38 in the granite, biotite granite and the pegmatite. The values of covariation in all instances are less than 15% implying that there is no linear relationship between porosity and density in these rocks.

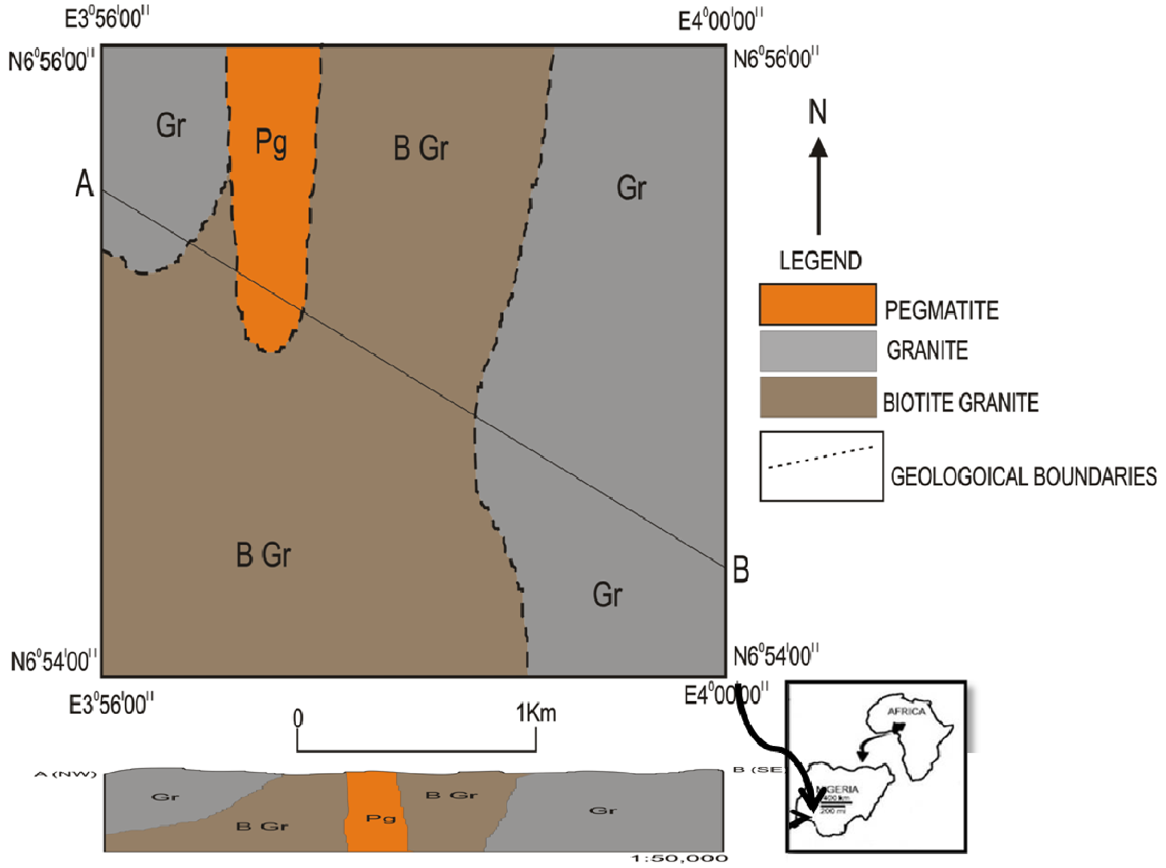

Fig 2: Geological map and cross section of the study area, the dominant rock type in the study area is granite.

Table 1: Rock samples density, moisture content and porosity.

LOC	ww	Dw	mc	d	Buw	duw	vi	Φ
Granite								
L 1a	377.77	368.93	2.4	2.73	25.63	25.03	0.065	6.11
L 1b	377.77	368.93	2.4	2.73	25.63	25.03	0.065	6.11
L2a	734.79	732.63	0.29	2.74	26.78	26.7	0.008	0.8
L2b	247.07	247.07	1.16	2.72	26.27	25.96	0.032	3.08
L2c	247.07	247.07	1.16	2.72	26.27	25.96	0.032	3.08
L3a	621.29	618.14	0.51	2.73	26.56	26.43	0.014	1.37
L3b	646.44	644.51	0.3	2.72	26.59	26.51	0.008	0.81
L3c	418.92	416.03	0.69	2.7	26.18	26	0.019	1.84
L4	635.78	632.35	0.54	2.71	26.33	26.18	0.015	1.45
L9	311.52	300.74	3.58	2.72	25.17	24.3	0.097	8.88
L11	319.1	317.37	0.55	2.69	26.18	26.04	0.015	1.45
L12	1528.3	1522.15	0.4	2.73	26.61	26.5	0.011	1.09
B.Granite								
L6	332.27	328.15	1.26	2.7	25.98	25.66	0.034	3.28
L7a	202.22	200.52	0.85	2.74	26.45	26.23	0.023	2.27
L7b	327.18	324.47	0.85	2.72	26.33	26.11	0.023	2.22
L7c	327.18	324.47	0.85	2.72	26.33	26.11	0.023	2.22
L8	326.14	322.5	1.13	2.75	26.43	26.13	0.031	3.01
L13	1528.3	1522.15	0.4	2.7	26.26	26.16	0.011	1.08
L14	134.02	132.99	0.77	2.73	26.43	26.23	0.021	2.07
L15	176.23	175.01	0.7	2.71	26.3	26.12	0.019	1.86
Pegmatite								
L5	137.09	133.64	2.58	2.71	25.49	24.85	0.07	6.54
L10	366.18	360.02	1.71	2.73	25.99	25.55	0.047	4.46
L10b	651.19	637.04	2.22	2.7	25.52	24.97	0.06	5.65
L10c	629.18	620.45	1.41	2.71	26.01	25.65	0.038	3.68

ww- wet weight, dw- dry weight, mc-moisture content, d-density, buw-bulk unit weight, duw- dry unit weight, vi-void index, Φ- porosity

The anomaly profiles.

Anomaly profiles are shown in Fig 4 along the sectional line. AB and CD profiles were specifically chosen along the pegmatite outcrop. The estimated anomaly along profile is 0.08, 0.07, 0.1 and 0.09 g/cm^3 for location 9, 10, 10b and 10c respectively. The density contrast between the locations shows a decrease from L9 to L10, then an increase to

L10b and subsequent decrease to L10c; the contrast from L10 & L10c is approximately 0.02g/cm^3. The anomaly type is thus named an S-type anomaly, with a concave upward geometry over the pegmatite outcrop. For profile CD, the density contrast increases from L10 to L10b, then decrease on L10c and subsequently rises and fall to L13 and L14 respectively. The density contrast decreases by 0.01g/cm^3 from L10b to L10c and decreases by 0.03g/cm^3 from L13 to L14 and L10b to L10. The anomaly profile was described as the M- type.

Table 2: Calculated statistical parameters for densities of the different rock types in the area

Rock Type	Pegmatite	Granite	Biotite granite
No of Samples	4	12	8
Average	2.7125	2.72	2.72125
Minimum	2.7	2.69	2.7
Maximum	2.73	2.74	2.75
Median	2.71	2.72	2.72
Mode	2.71	2.73	2.7
Standard	0.012583	0.014142	0.018077215

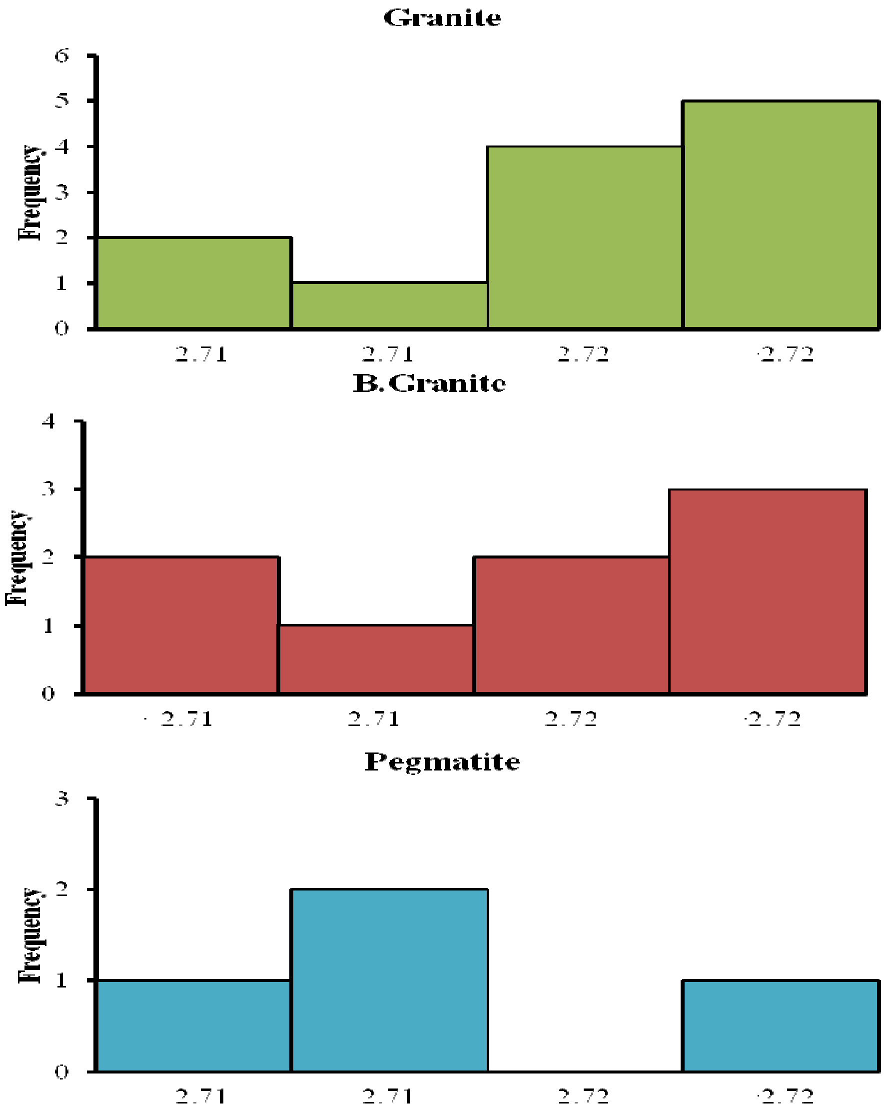

Fig 3: Densities of different rock types in the study area, the highest density value was recorded in the Biotite Granite with the lowest in the Granite

The anomaly profile for EF was named concave up because the density contrast increases from L12 to L11 and decreases to L15. The difference in the density contrasts is 0.04 g/cm^3 and 0.02 g/cm^3 from L12 to L11 and L11 to L15 respectively. Zig-zag type of anomaly was observed along the profile GH where the density contrast increase from L3a to L3c, then decreases to L2a and increase to L2b. The density contrast differs by 0.02g/cm^3 on the average in all instances along the profile line. For profile IJ, the density contrast decreases from L4 to L4b. There is no difference in the density contrast from L5 to L4 where the anomaly flattens out while it decreases to L4b by $0.02g/cm^3$. The anomaly profile was described as flat top-anomaly. The anomaly profile along KL increases from L8 to L6 producing a kind of stair case geometry. The density contrast increases on the average by $0.02g/cm^3$.

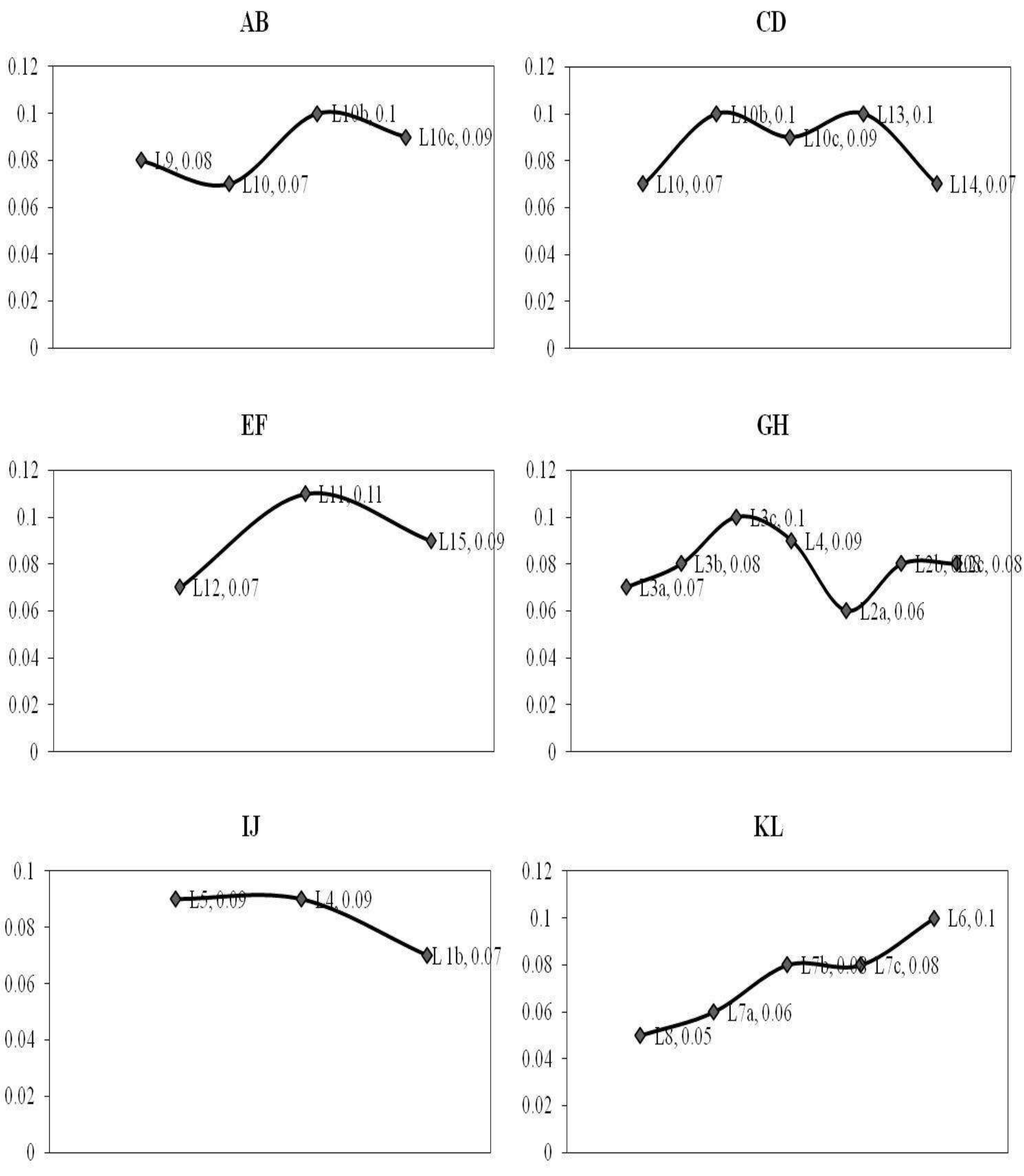

Fig 4: The modeled gravity anomaly along profile shown in Fig 1. Anomaly type includes S-, M-, Zig-Zag, Flat top, Stair case and Concave up anomalies.

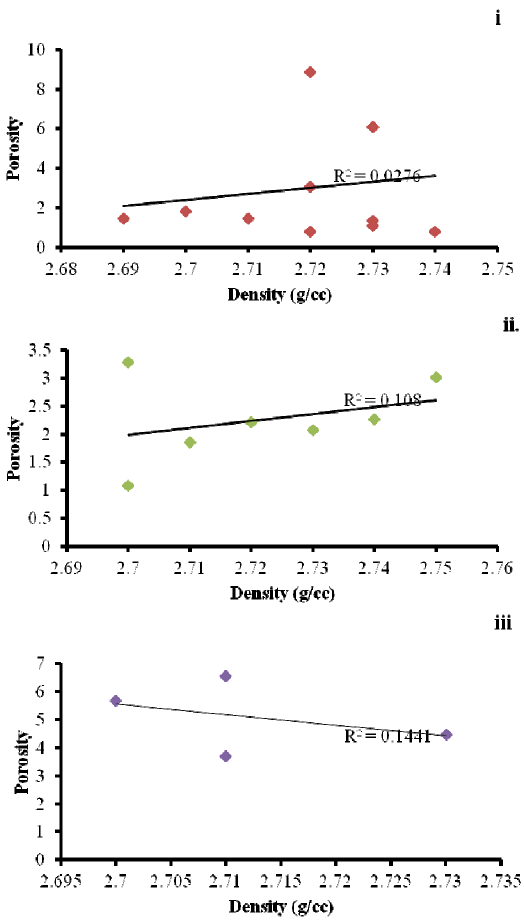

Fig 5: Linear regression analysis between porosity and density. R^2 is the coefficient of determination or co variation which shows how much of the other variable is determined by the other. The plot between the porosity and density for (i) the granites (ii) biotite granites (iii) pegmatites.

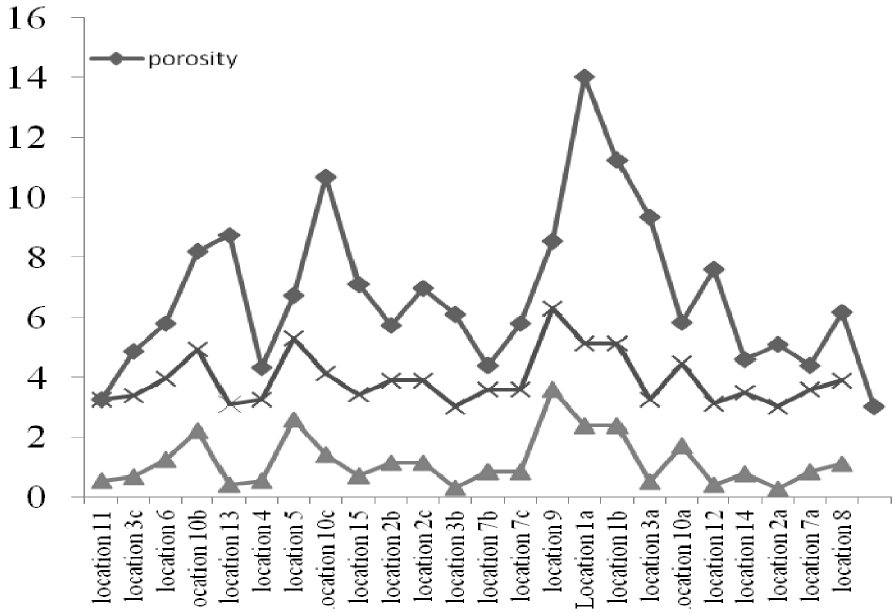

Fig 6: Plot of Porosity, density and Mositure content highlighting the dependence or variation of the varibale.

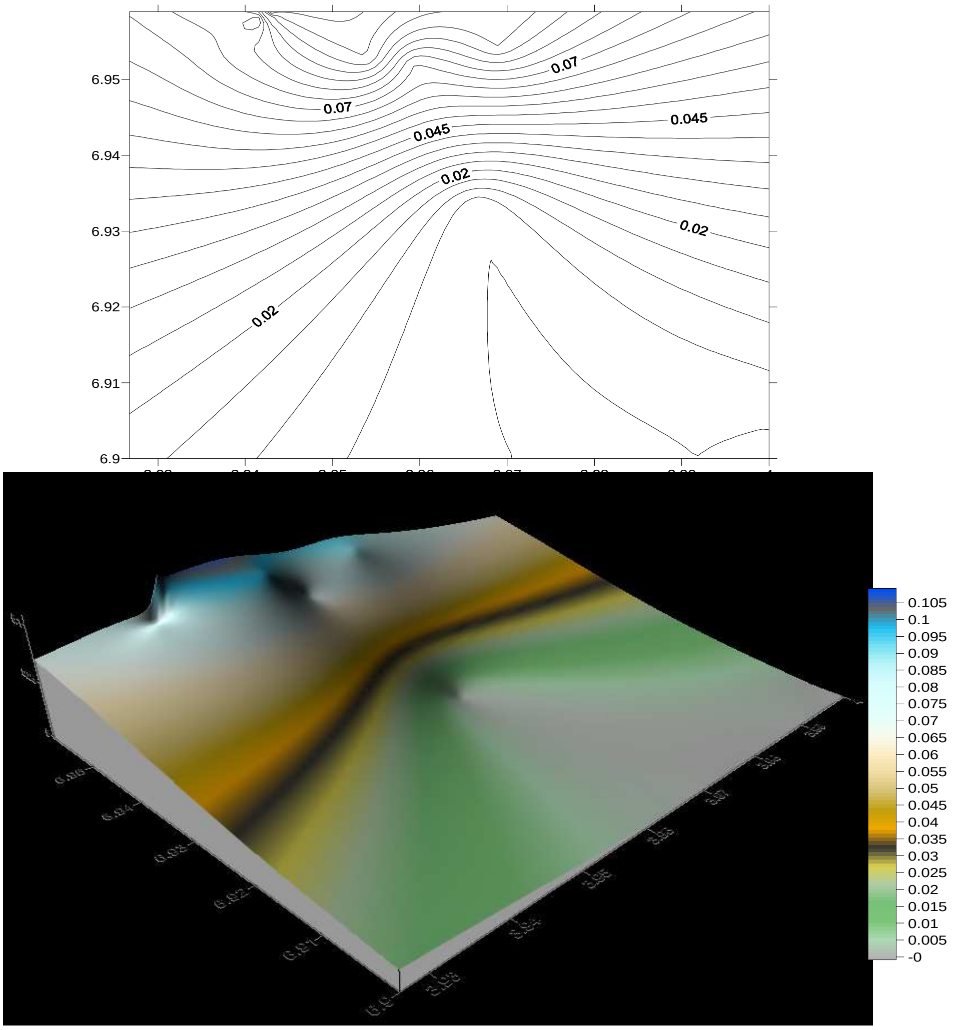

Fig 5a: Modeled gravity anomaly map of the upper part of the study area.

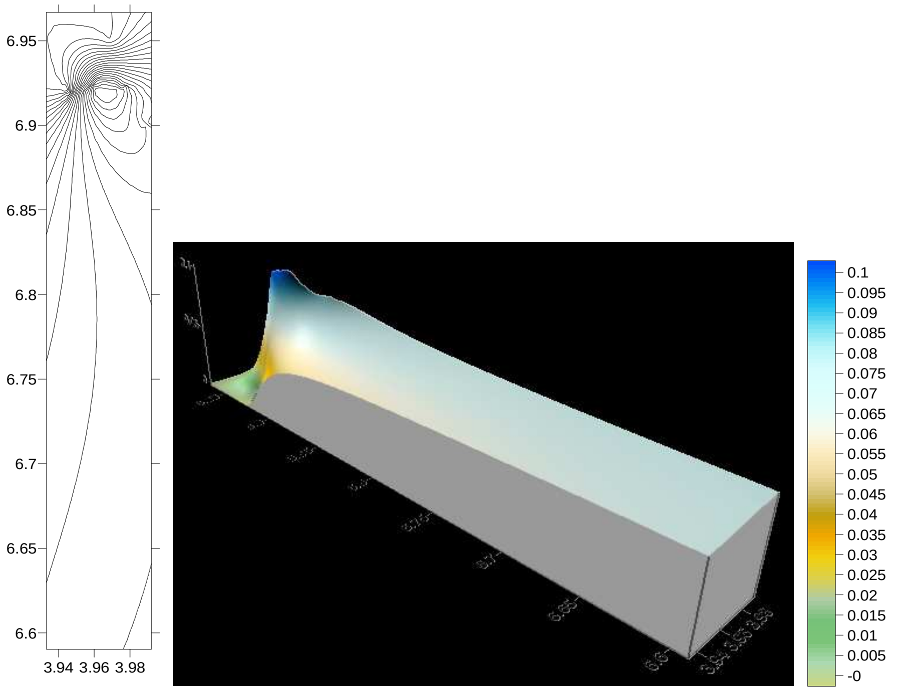

Fig.5b: Modeled gravity anomaly map of the lower part of study area.

Density contrast exist where the relative difference of two rock types can be determined, especially in situations where the rock lie over one another, (common situation in sedimentary basins), in basement complex, where hard rock are outcropped, the rock are thought to be underlain by the continental crust. Densities contrast in such instance represents the difference in density value of the rock and the crust. The granite solidus is approximately 20km beneath the earth surface. This implies the depth to the crust of the rock can be roughly estimated. The difference of the height above the sea level from the GPS and the 16km in to the sub surface which represents the value next to the granite solidus is the depth of the outcrop to the continental crust. It is therefore plausible to represent the depth of the pegmatite intrusion in the same manner since it is granitic in composition.

The 3D anomaly map of the upper part of the study area (Fig. 5a) shows a very high density anomaly at the NNW part and significant decrease in density contrast at the extreme SE end. At the eastern and western boundaries, it is moderately high. The areas of very high density contrast coincides with the upward concave trend on anomaly profile AB and CD. On the lower map of the study area (Fig. 5b), the peak in density contrasts recorded on the N on the map may overlap with the lowermost boundary of the pegmatite outcrop. This trend coincides with IJ profile of Fig 4. The density value flattens out on the other part of map suggesting homogeneity of the density contrast.

The anomaly profiles when inverted would express the geometry of the continental crust at each of the places. The density contrast between the continental crust and rocks suggests that the outcrops are buried approximately 16km below the earth surface, before the granite solidus. Over the pegmatite outcrop, the profiles are concave upward suggesting the continental crust to be concave down. This means the pegmatite intrusion are not tabular (vertical dykes) but circular intrusion in map view. It is circular intrusion in the host rock, biotite granite and granite.

Determining what factor controls the density of the rock type is important in the accurate prediction of gravity anomaly. From the plot of density against porosity, the amount of pore spaces in the rock of the study area has no direct linear relationship with porosity as suggested by the low linear correlation between them (Fig.5). In places where porosity is high the moisture content is also high and sometimes the density (Fig. 6), the relationship between moisture content and porosity is envisaged as the amount of water in a rock is governed by the availability of pores to contain them.

The ambiguity of interpreting the potential gravity anomalies is dependent on an infinite number of sources. The ambiguity can be reduced by utilizing all external constraint on the nature and form of the anomalous body (Lines *et al.* 1988). The estimation of the gravity anomaly along profile is one way of reducing ambiguity associated with the 3D anomaly maps.

The relative variation in the density of rocks in the study area is relatively small, 0.0075g/cm^3 and there is considerable overlap in the measured densities. Hence knowledge of rock density alone will not suffice to determine the gravity anomaly. The small variation in rock densities implies that the spatial variation in the observed anomalies caused by geological structures will be quite small and difficult to detect.

CONCLUSION

The study area is underlain by Granite, Biotite granite, and circular Pegmatites intrusions which outcrop in the Granites. The pegmatite of the study area contains economic minerals such as quartz, feldspars, muscovite, and tourmaline. The calculated densities of the rocks include Granite, mean density of 2.72 gm^{-3}; Biotite granite, mean density of 2.7213gm^{-3}; and Pegmatite, mean density of 2.7125 gm^{-3}. The variation in density is approximately 0.0075g/cm^3.

Anomaly types described along selected gravity profiles include *S, M, Concave up, UL, Zig-Zag Flat top, and Stair case* anomalies. The outcrops are buried to approximately 16km into the subsurface away from the granite solidus.
Gravity anomalies in the study area are associated with mineralization and ambiguity in the anomalies calculated result from variation in the porosity of the different rock samples. Future work may embrace a larger survey area and statistical analysis of parameters influencing the density of rocks. Whole rock analysis can provide information on the temperature of melting and subsequently different densities types.

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REFERENCES

[1] A.A Elueze, *Journal of Nigeria Mining and Geoscience Society*,**1981** Vol: 18 Pp5-7
[2] A.S. Ekwere, A. Edet, *Advances in Applied Science Research*, **2012**, 3 (1): 312-318
[3] Caby, Betrand, J.M.L, Black, R, *Pan-African ocean closure and continental collision in the Hoggar-Iforas segment. Central Sahara*, In Precambrian Plate Tectonics, edited by A. Kroner, Elsevier Amsterdam, **1981**,407-434.
[4] C. Subrahmanyam, R.K, Verma, *Journal of Geophysics*, **1981** Vol 49, 101–107.
[5] D,E. Ajakaiye, K. Burke, *Tectonophysics*, **1972**, Vol 16: 103-115
[6] D.E. Ajakaiye, J.F. Sweeney, *Tectonophysics*, **1974** Vol 24:331-341
[7] E.E Bassey, *Advances in Applied Science Research*, **2012**, 3 (2):994-1007
[8] H. Henkel, *Pure and Applied Geophysics (Pageoph*.) **1976** Vol 114, 235–249.
[9] J.D. Falconer, *The geology and geography of northern Nigeria* Macmillian, London., **1911** pp295.
[10] J.I. Omada, O.O Olorunfemi, *Advances in Applied Science Research*, **2012**, 3 (1):393-398
[11] J.O.Akintola, *Rainfall Distribution in Nigeria*1982-1983, Impact Publishers Nigeria Limited, Ibadan , Nigeria., **1986**.
[12] L.R. Lines,A.K. Schultz, and S. Treitel, *Geophysics*, **1998** Vol 53, 8-20
[13] M.A.Rahaman, "*Classification of Rocks in the Nigeria Precambrian Basement Complex*. Annual Conference of Nigerian Mining Geological and Metallurgical Society. Dec. **1971**. Kaduna, Nigeria
[14] M.I Oden, E.E Igonor, *Advances in Applied Science Research*, **2012,** 3 (3):1582-1588
[15] M.O. Oyawoye, *The basement complex of Nigeria*. *In African geology*, university press Ibadan, dessauvagier, T.F.J and whiteman, A.J. (eds), **1972**. 67-103.
[16] M. Rider, *The Geological Interpretation of Well Logs* (2nd edn). – Whittles Publishing, Caithness, **1995**.
[17] N. Rast, *The initiation, ascent and emplacement of Magmas* In: Newall and Rast (Editors), mechanism of Igneous Intrusion. Gallery Press, Liverpool,**1970**: 339-362
[18] O. Serra, *Fundamentals of well log interpretation*, Vol 1: the acquisition of logging data. – Dev. Pet. Sci., 15A, Elsevier, Amsterdam, **1984**.
[19] P.G.Cooray, "*A Note on the Charnockites of the Ado-ekiti Area, Western State, Nigeria*". Geology of Africa T.F.J Dessauvagie and A.J. Whiteman (eds.). 45-54. University Ibadan: Ibadan, Nigeria., **1972**.
[20] R.T. Ranganai, *Geophysical Investigations of the Granite-Greenstone Terrain in the South-Central Zimbabwe Archaean craton*. PhD Thesis, University of Leeds. Leeds, UK, **1995**, 288.
[21] S. Fricke, Schön J, *Praktische Bohrlochgeophysik*. – Enke im Georg Thieme Verlag, Stuttgart. **1999**
[22] S.S.Dada, T, L. Briqueu, U. Harms, J.R. Lancelot, G. Matheis, *Chemical Geology* **1995** (124): 233-252
[23] S.S. Dada, *Precambrian research* **1998** Vol 87:65-74