Communication in Physical Sciences, 2022, 8(3):355-363

Characterization of Subsurface Densities Using Aerogravity Data of Okigwe and Environs

Isaac Owoicho Agada, Magnus Uzoma Igboekwe and Faustinus Chukwunweike Anyadiegwu

Received: 25 January 2022/Accepted 01 July 2022/Published online: 05 July 2022

Abstract: *Density and its variations across rock materials govern gravity anomalies. As an important physical property of geologic materials, knowledge of rock densities provides vital information on subsurface structure and explorations. The ssstudy was carried out to model gravity anomalies and analyse the varying densities of subsurface materials within Okigwe and Environslocated between Latitudes 5˚30'N and 6˚00'N, and Longitudes 7˚00'E and 7˚30'E in South Eastern Nigeria. Using Oasis Montaj geophysical data processing tool, aerogravity dataset for Okigwe and environs as contained in the Okigwe aerogravity sheet 312 obtained from Nigeria Geologic Survey Agency (NGSA) was analysed, mapped, profiled and modelled inversely to reveal the subsurface with varying and unique densities. There are huge masses of igneous/ gneiss intrusions with densities of 2.80g/cm^3 in a diagonal array from the NE to SW of the study area, with locations such as Ihube, okigwe town and Umuna featuring strategically. The entire Okigwe and environs is underlain by a thick Precambrian basement complex, having varying densities of 2.67g/cm^3 and 2.76g/cm^3. The huge basement complex of the study area is overlaid with sediments of various densities, ranging from sandstones (2.25g/cm^3), and clay/shale/laterite (1.98g/cm^3). At the NW extreme and SE wing around Obowo, Umuahia and environs, the subsurfaceis dominated by low density materials as projected by the negative gravity signatures observed in the Bouguer anomaly map. Materials with the highest densities were observed at the NE axis around ihube, Okigwe, the southern part of Isuochiand their environs.*

Keywords: *Density, Gravity, Okigwe, Intrusion, Sedimentary, Basement*

Isaac Owoicho Agada*
Department of Physics, Michael Okpara University of Agriculture, Umudike, Abia State, Nigeria
Email: agadaisaac45@gmail.com
Orcid id: 0000-0002-2483-8938

Magnus Uzoma Igboekwe,
Department of Physics, Michael Okpara University of Agriculture, Umudike, Abia State, Nigeria
Email: igboekwemu@yahoo.com
Orcid id:

Faustinus Chukwunweike Anyadiegwu
Department of Physics, Michael Okpara University of Agriculture, Umudike, Abia State, Nigeria
Email: fzinoz@gmail.com
Orcid id: 0000-0002-9589-4806

1.0 Introduction

Gravity surveying is based on Newton's law of universal gravitation and the second law of motion and measures the variations of the earth's gravitational field caused by differences in the density of sub-surface rocks (Reynolds, 1997 and Lowrie, 2007). It is hence the measurement of variation in acceleration due to gravity as the technique is sensitive to variations in rock densities (Omosanya *et al*., 2012, Alsadi and Baban, 2014). As such, an appreciation of the factors that affect density will aid the interpretation of gravity data.

According to Newton's law of universal gravitation, the force of attraction between two bodies of known mass is directly proportional to the product of the two masses and inversely proportional to the square of the distance between their centres of mass (Reynolds, 1997, Alsadi and Baban, 2014). Consequently, the greater the distance separating the centres of mass, the smaller the force of attraction between them. Hence,

Force = gravitational constant × mass of the earth (M) × mass (m) /(Distance between masses (R))^2

$$F = G\frac{mM}{R^2} \quad (1)$$

where G is the gravitational constant,

G = 6.67 x 10-11 Nm^{2}kg^{-2} (2)

In the Newton's Second law of motion, a force (F) is equal to mass (m) multiplied by its acceleration. If the acceleration is in a vertical direction, then it is due to gravity (g). In theoretical form, Newton's Second law of motion is expressed as:

Force (F) = mass (m) × acceleration (g)

F = mg (3)

Therefore, substituting (3) into (1)

$$mg = G\frac{mM}{R^2} \quad (4)$$

This shows that the magnitude of the acceleration due to gravity on Earth (g) is directly proportional to the mass (M) of the Earth and inversely proportional to the square of the Earth's radius (R). Theoretically, acceleration due to gravity should be constant over the Earth. In reality, gravity varies from place to place because the earth has the shape of a flattened sphere, rotates, and has an irregular surface topography and variable mass distribution.The normal value of g at the Earth's surface is 980 cm/s^2.

The gravity method is a secondary method for hydrogeological and subsurface investigation while resistivity methods such as Vertical Electrical Sounding and Electrical Resistivity Tomography/imaging are considered as Primary methods of surveying the earth's crust and beneath, groundwater investigation, mapping of leachate and contaminant plumes, etc (Igboekwe *et al.*, 2021, Lowrie, 2007 and Anyadiegwu *et al.*, 2021). Furthermore, gravity method is used in detecting the sub-surface structures, depth of the basement and the sedimentary cover thickness (Arafa *et al*., 2018).

The density of rock materials is a major property that influences gravity distribution in the earth (Anyadiegwu *et al.*, 2021). It is a measure of how compact an object or rock material is. Density is expressed as the ratio of the mass of an object to its volume (Omosanya *et al*., 2012). That is,

Density (ρ) = m/v (5)

where m is the mass of rock, v is the volume of rock

Hence, ρv = m (6)

This presents a linear relationship between mass and density. The higher the mass of rock material, the higher its density and hence, the more compact the rock material (Anyadiegwu *et al.*, 2021). As rightly stated by Aspler *et al*. (2003) and Alsadi and Baban (2014), geological structures can cause gravity anomalies. Below in Table 1 are varying rock densities of some rocks.

1.1 Study location

The study covered areas within Okigwe and environs, located between Latitudes 5˚30'N and 6˚00'N, and Longitudes 7˚00'E and 7˚30'E in South Eastern Nigeria. The research was carried out to model gravity anomalies and analyse the varying densities of subsurface materials within Okigwe and Environs. This would be made possible through appropriate interpretation of negative and positive gravity signatures in Bouguer anomaly map and profile models.

Okigwe and environs as captured by the Okigwe aerogravity datasheet coverparts of Abia (Umuahia) and Imo states with a significant part of the sheet hosting communities in Imo state. As seen in Fig. 1 and Fig. 2, the South Western wing of the sheet hosts Owerri and flanks Okwelle and Ikembara within the prolific aquifers of Ogwashi and Benin geologic formations in terms of groundwater productivity. In Fig. 2 below, Communities such as Okigwe, Ihube, Ogbabu and the Southern part of Isuochi are found in the North East wing of the sheet. The North Eastern wing is underlain with Nkporo, Manu, Ajali and a little of Asu river group geologic formations. The North Western flanks arcs Orlu in Imo statetoUmuchu, located within the Ogwashi, Ameki and Imo shale geologic formations (Onyewuchi and Ugwu, 2017). The South Eastern part of the Okigwe aerogravity sheet consists of parts of Bende, Umunneochi, Umuahia and Obowo, underlain with Ogwashi, Ameki, Imoshale and a bit of Ajali geologic formations.

Table 1: Densities of common Geologic materials

Material type	Density range (Mg/m^3)	Approximate average density (Mg/m^3)
Sedimentary rocks		
Alluvium	1.96-2.00	1.98
Clay	1.63-2.60	2.21
Gravel	1.70-2.40	2.00
Loess	1.40-1.93	1.64
Silt	1.80-2.20	1.93
Soil	1.20-2.40	1.92
Sand	1.70-2.30	2.00
Sandstone	1.61-2.76	2.35
Shale	1.77-3.20	2.40
Limestone	1.93-2.90	2.55
Dolomite	2.28-2.90	2.70
Chalk	1.53-2.60	2.01
Halite	2.10-2.60	2.22
Glacier ice	0.88-0.92	0.90
Igneous rocks		
Rhyolite	2.35-2.70	2.52
Granite	2.50-2.81	2.64
Andesite	2.40-2.80	2.61
Syenite	2.60-2.95	2.77
Basalt	2.70-3.30	2.99
Gabbro	2.70-3.50	3.03
Metamorphic rocks		
Schist	2.39-2.90	2.64
Gneiss	2.59-3.00	2.80
Phyllite	2.68-2.80	2.74
Slate	2.70-2.90	2.79
Granulite	2.52-2.73	2.65
Amphibolite	2.90-3.04	2.96
Eclogite	3.20-3.54	3.37

Culled from Pals et al. (2006) and Alsadi and Baban (2014)

2.0 Materials and Methods

The Okigwe sheet 312 is an integral part of the Nigeria Aerogravity Sheet Index and its soft copy was procured from the Nigeria Geologic Survey Agency (NGSA) in Abuja. The data were analysed with the aid of Oasis Montaj Mapping and geophysical

data processing software which enabled inverse modelling of gravity datasets. The system can perform complex processing, analysis, visualization, mapping, and integration capabilities, enabling the user to edit, map and interpret the results of analysed data. With the use of these efficient tools, models with 2-D and 3-D images of the sub-surface were produced.

Models and images produced include the gravity data plot, 3-D surface map of the study area and the Bouguer anomaly map. Fundamental in this study is the Bouguer anomaly map which represents the corrected gravity data. This is important because anomalies within the gravitational field can be used to determine how mass is distributed following equation 4. The Bouguer anomaly map was profiled in 3 places chosen particularly to harness maximum information on the subsurface and cuts across the two main lithologies of sedimentary and basement complex, including suspected structures. These profiles were then modelled to produce three 2-D images of the subsurface at various depths ranging from 1000 to 3000m.

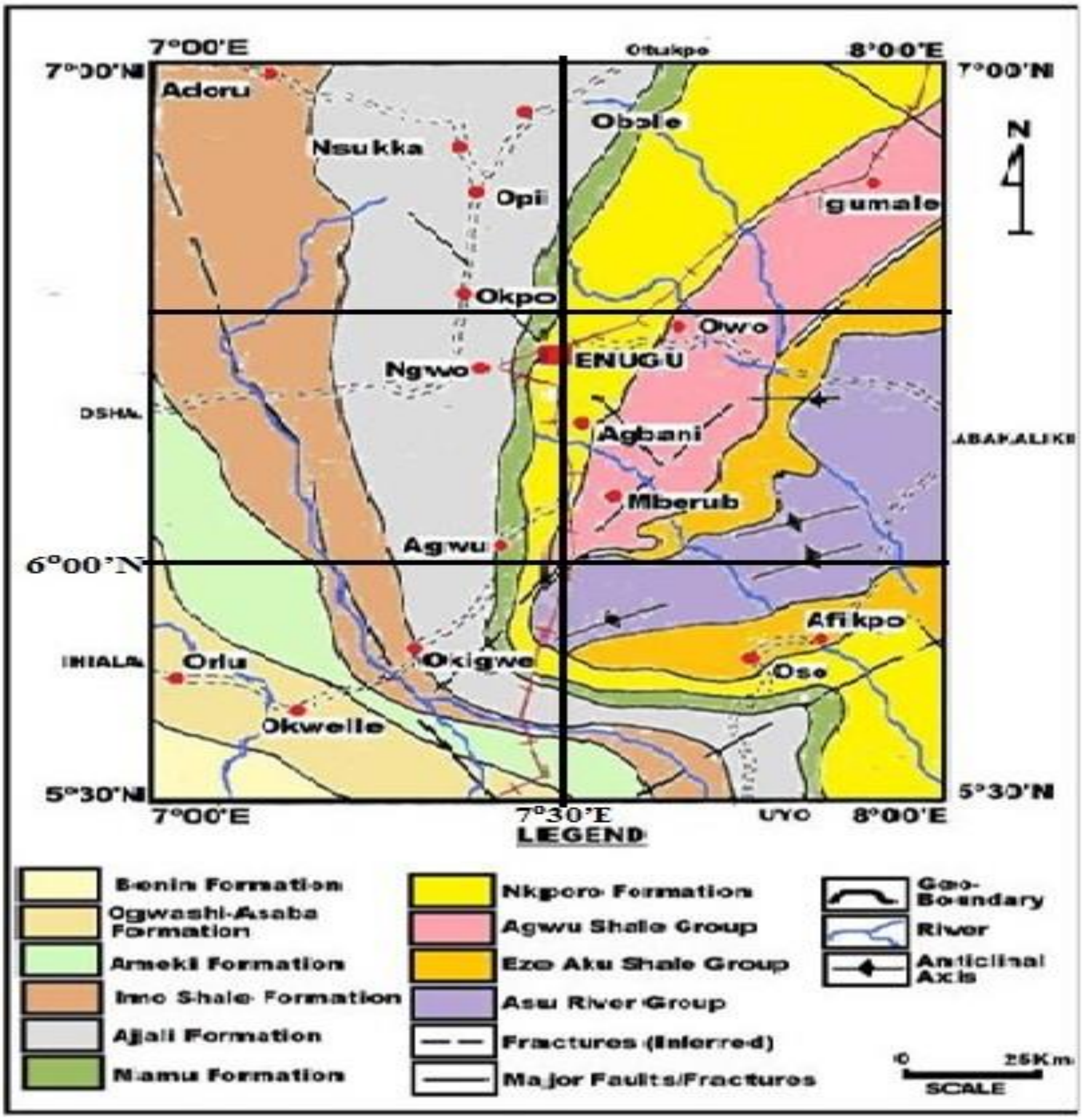

Fig. 1: Geologic Map of Okigwe Gravity Sheet 312. Adopted from Onyewuchi and Ugwu (2017)

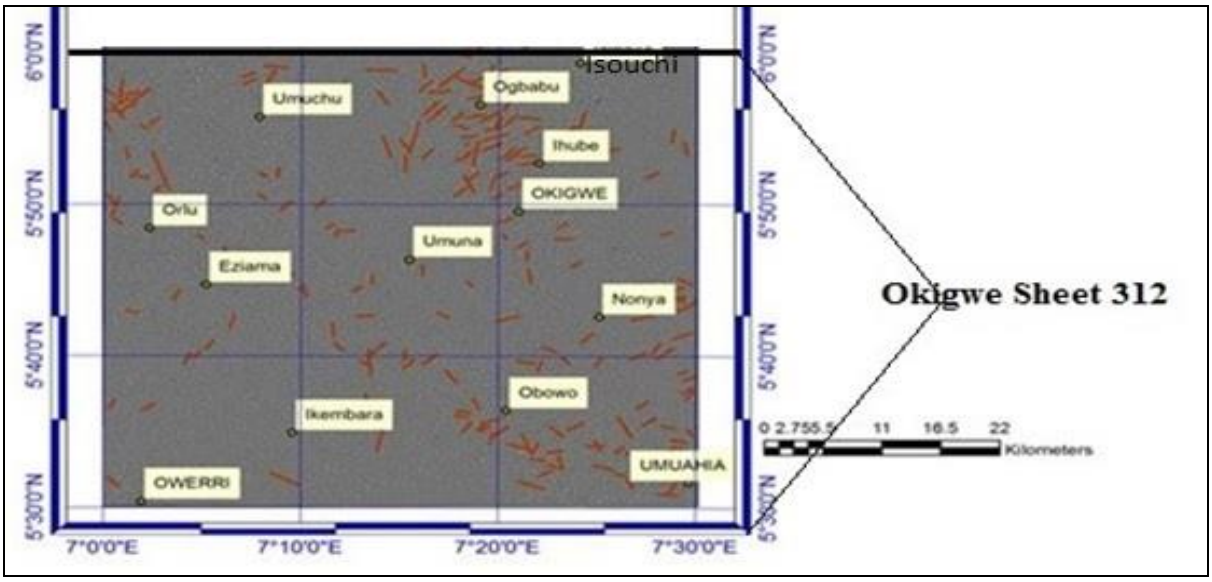

Fig. 2:MajorCommunity distribution within Okigwe Gravity Sheet 312 Adopted from Onyewuchi and Ugwu (2017)

3.0 Results and Discussion

Aerogravity data plots and 3-D surface maps produced for Okigwe sheet 312 revealed unique gravity features. Gravity lows (negative gravity signatures) of between 0µGal and -12µGal were identified at the North-Western and South-Eastern wings of the sheet while the North-Eastern to South-Western flanks are regions with high gravity values of between 0µGal and 26.1µGal as presented in Figs. 3 and 4 .

The areas with blue coloration in Fig. 4 below are indicative of low-density materials, responsible for the gravity lows observed.

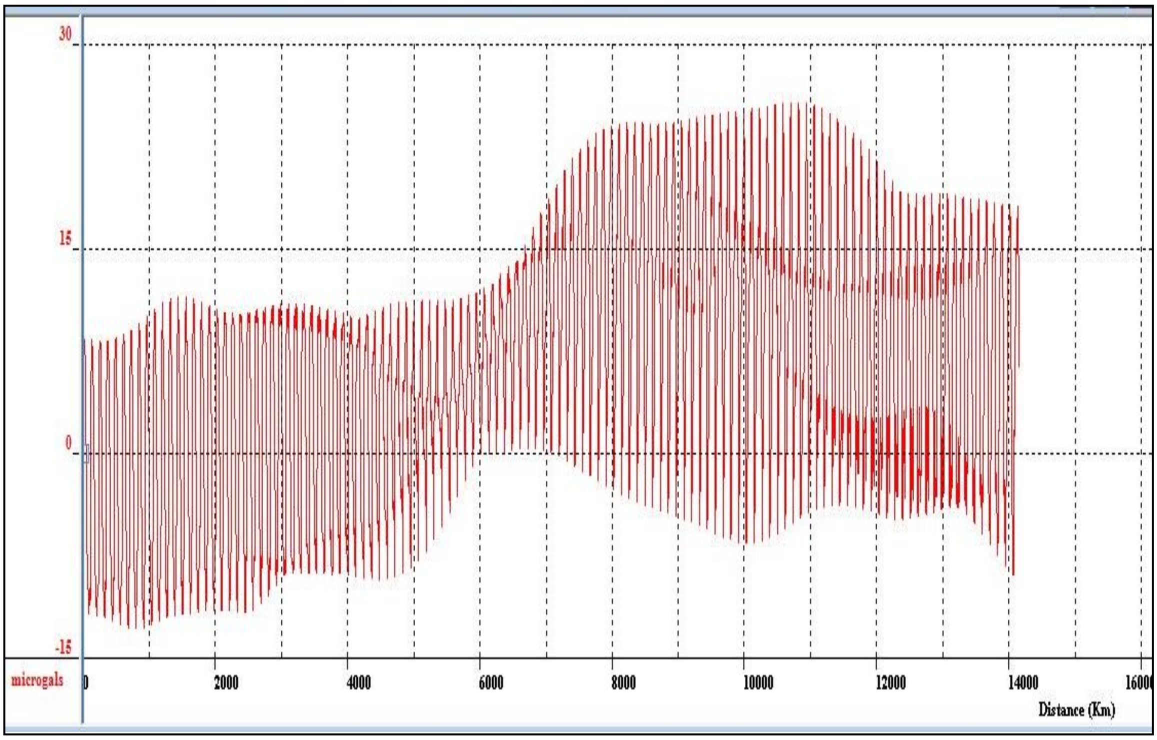

Fig.3: Gravity Data Plots

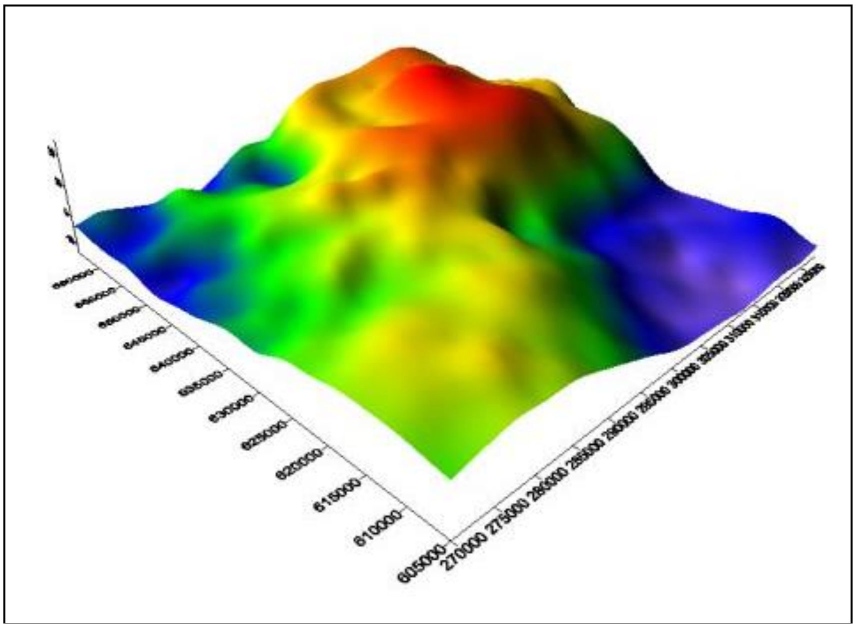

Fig. 4: 3-D Surface Map of Okigwe Gravity Sheet 312

It is obvious from Fig. 3, Fig. 4 and Fig. 5that there are negative gravity signatures at the South-Eastern and North western wings.The Bouguer gravity anomaly map (Fig. 5) below indicates some gravity lows which represents low amplitude.The presence of low density materials is responsible for gravity lows (negative gravity values) (Pal *et al.*, 2006). The gravity lows are associated with anticline structures of granitic and igneous masses which indicate the intrusive nature of these masses, with these intrusions occurring during different orogenic cycles (Pal *et al.*, 2006). It can therefore be said that these negative gravity values represent low density materials such as sand, clay, silt, shale, etc.

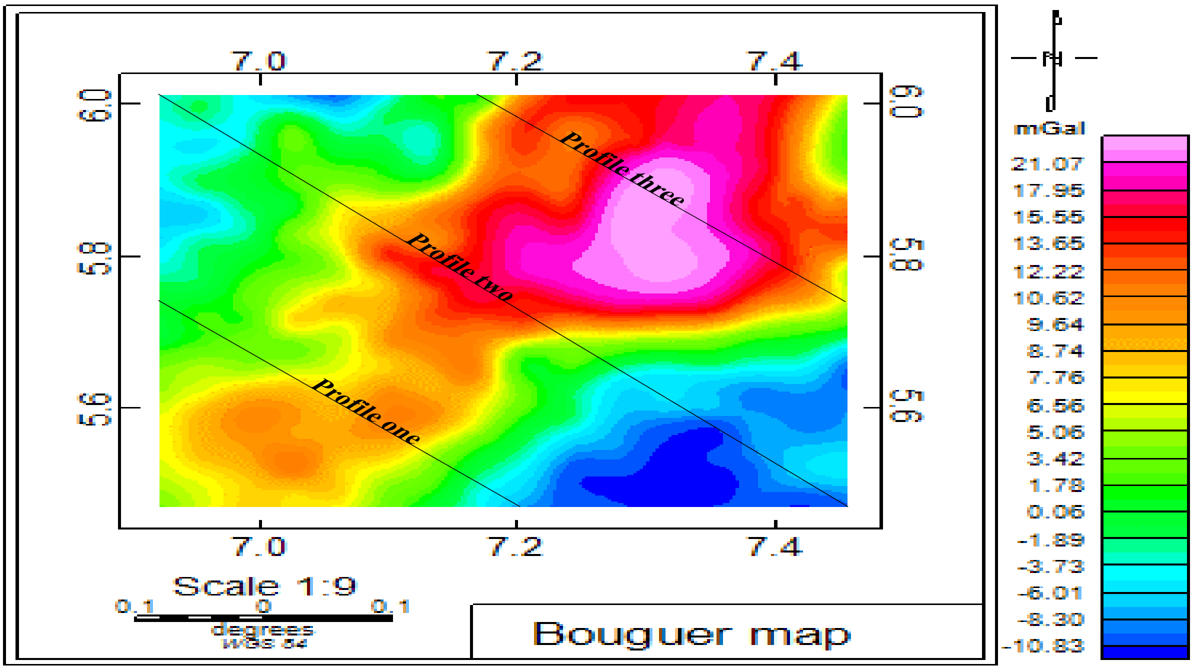

Fig. 5: Bouguer Gravity map

A greater part of the region is made up of high density materials as seen in the 3-D surface map and the bouguer map. These materials are responsible for the gravity highs observed. The high prolific aquifers of the Benin and Ogwashi formations in terms of groundwater production can be found around the South Western region of the sheet.

Modelling of the three (3) profile lines on Fig. 5 produced Fig 6, Fig. 7 and Fig. 8 representing profiles 1, 2 and 3 respectively. The 3 profile models all show igneous intrusions overlaid with basal sandstones. These intrusions result in the breaking and fracturing of overlying shale. These shale/ sandstone materials have secondary porosity and permeability, with the potential to harbour water. Such aquifers are usually of marginal to moderate yield in terms of groundwater production.

Profile 1 model as presented below in fig. 6 flanked the W and SW axis. The model revealed deep subsurface features such as the Precambrian basement with a density of 2.67and 2.73g/cm^3, igneous intrusions having a density of 2.80g/cm^3, sandstone with density of 2.25g/cm^3, and laterite/shale/clay with a density of 1.98g/cm^3.Places around Orlu and Eziama have been shown to have basement rocks of 2.67g/cm^3 which extends to the surface particularly near Orlu. SE end of the profile identifies Ikembara and its environs with basement rocks of 2.73g/cm^3, and has risen to a depth of about 249m near the surface. However, a sharp spike of the rock is close to the earth's surface at the NW and SE extremes of the profile. These near surface rocks and or extrusions could be seen as surface rocks, exposed as a result of erosion in the region. However, there is an intrusive mass of igneous rock with a density of 2.80g/cm^3 through the basement in the environs of Okwuelle in Imo state. In the theoretical and observed curve of the profile, it is obvious that the profile traversed an area that is composed of materials that are of high density, with the most dense material being in the neighbourhood of 10mGal while the least dense is about -12.5mGal within the Southwest.The thickest sedimentary layer is about 700m around the environs of Ikembara to the end of the profile. This profile penetrated a depth of about 1000m as seen in Fig. 6.

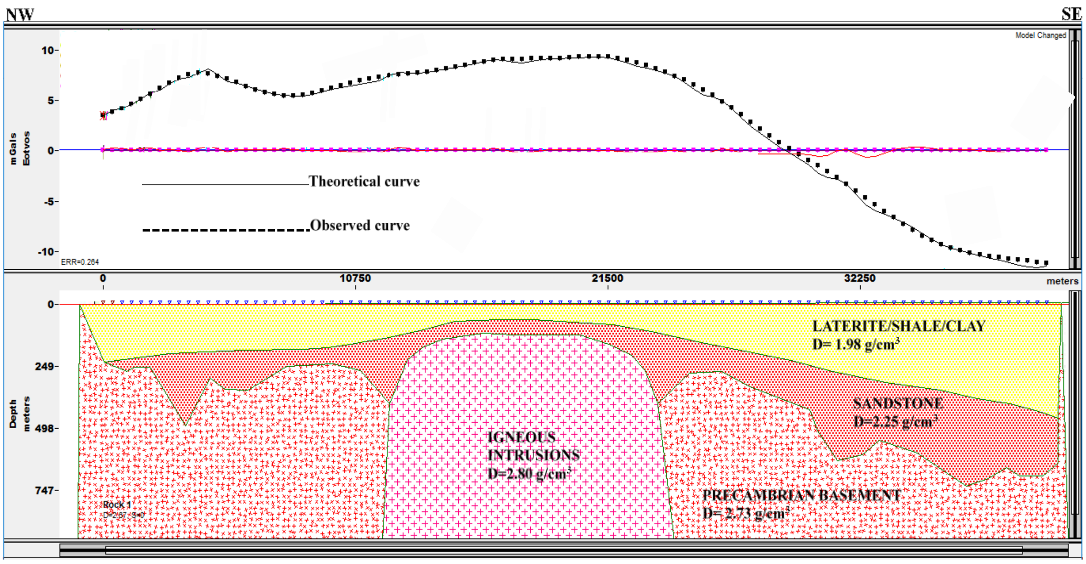

Fig.6: Two (2) Dimensional model from profile 1

Profile 2 model as presented below in fig 7 ran through the sheet diagonally from NW to SE at Umuahia. Just like profile 1, it showed deep subsurface features such as the Precambrian basement with a density of 2.73g/cm^3, igneous intrusions having a density of 2.80g/cm^3, sandstone with a density of 2.25g/cm^3, and laterite/shale/clay with a density of 1.98g/cm^3. Places around its extreme NW flank have basement rocks of 2.67g/cm^3 which extends sharply to the surface. The profile extends southward through the environs of Umuna, Obowo and Umuahia, with a greater proportion of the basement rocks at the NW part of the profile. The SE end of the profile identifies Obowo, Umuahia and environs with little traces of basement rocks of 2.73g/cm^3, and has risen to a depth of about 1250m near the surface. The subsurface around Umuahia and Obowo is predominantly sedimentary (sandstone, clay, shale and laterite) which are low density materials. However, a huge mass of igneous intrusion was also identified at the middle of the profile around the environs of Umuna. Considering the theoretical and observed curve of the profile, the area is underlain with materials that are of higher density, with the most dense material having gravity values of 20mGal while the least dense is about -9mGalaround the Southeast.It was observed that places around the SE flank surrounding Umuahia had a sedimentary thickness of about 2Km. The profile penetrated a depth of about 2000m as seen in Fig. 7.

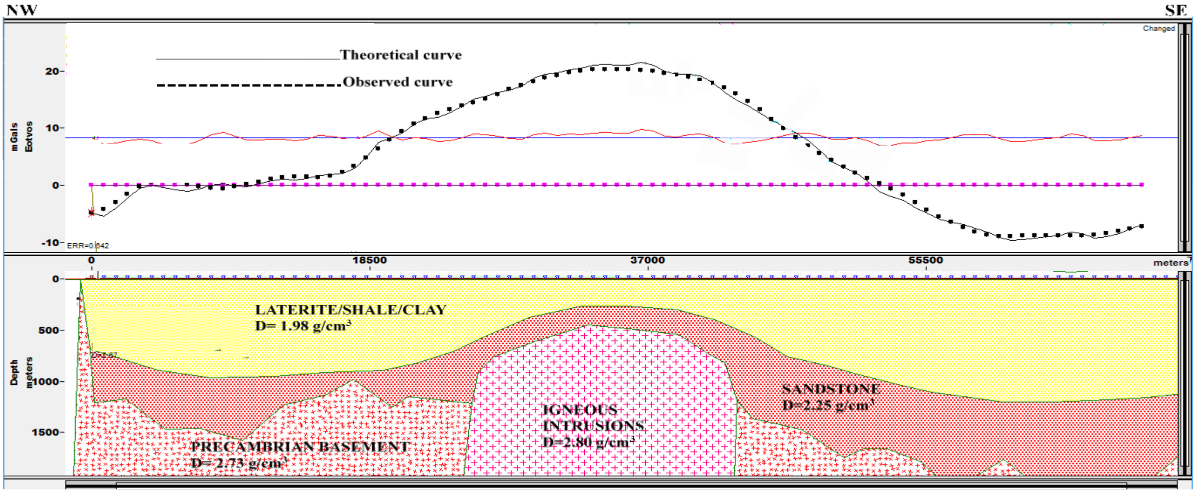

Fig. 7: Two (2) Dimensional model from profile 2

Profile 3 model as presented below in Fig.8 traversed the sheet from the North through Ogbabu, Ihube, Okigwe, Nonya and environs. Similar to profiles 1 and 2, it showed deep subsurface features such as the Precambrian basement with a density of 2.73g/cm^3, igneous intrusions having a density of 2.80g/cm^3, sandstone with a density of 2.25g/cm^3, and laterite/shale/clay with a density of 1.98g/cm^3.

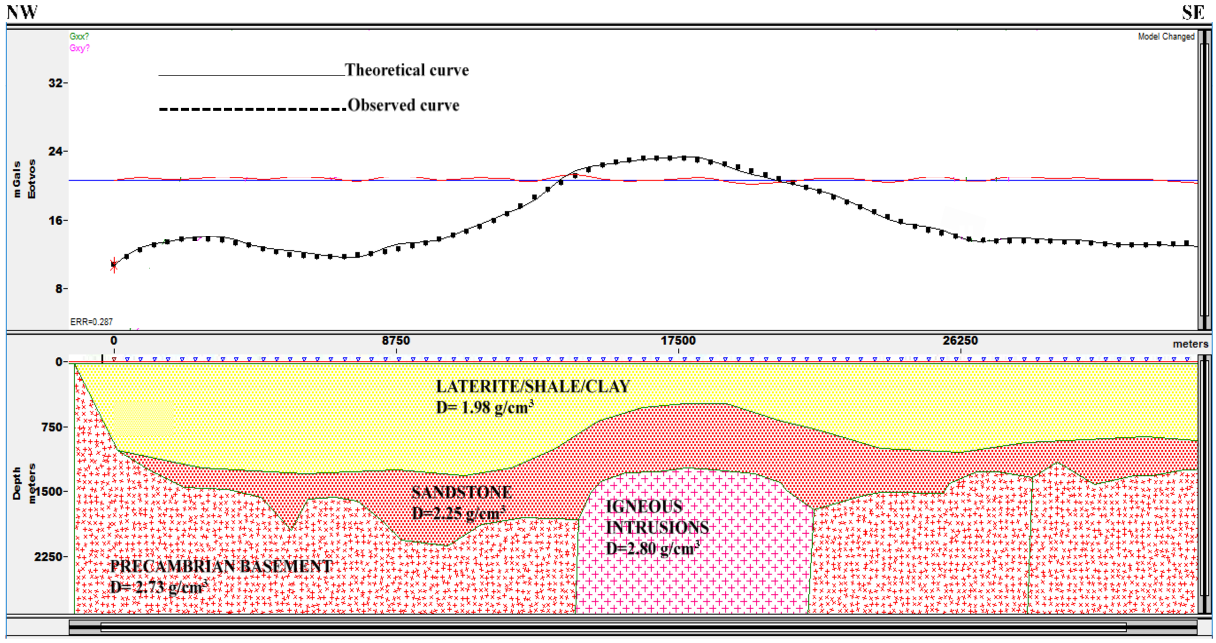

Fig. 8: Two (2) Dimensional model from profile 3

The model has a moderately even distribution of the basement rocks which rose to a depth of about 1000m near the earth surface, with an exceptional rise to the surface at the extreme northern point above Ogbabu. The region around Ihube and Okigwe has a large igneous intrusion. the entire region is underlain by high-density materials which confirmed the high gravity signatures observed in the Bouguer map.

A careful analysis of the graphical representation of the model in fig. 8, revealed that the profile traversed highly dense materials with the highest gravity values of about 24mGal while the least dense is about 11mGal within the Southwest. All values are within the positive gravity anomaly.The profile penetrated a depth of about 3000m.

The density of rock material shown in the gravity map and profile models provide insight into the lithology of the deep subsurface.

4.0 Conclusion

Okigwe and environs as covered in the Okigwe aerogravity sheet have 21.07mGal and -10.83mGal as maximum and minimum gravity values respectively. There are huge masses of igneous intrusions with densities of 2.80g/cm^3 in a diagonal array from the NE to SW of the study area with locations such as Ihube, Okigwe town and Umuna featuring strategically in this array. These intrusions could be a result of plutonic intrusions through the basement or volcanic eruptions. The entire Okigwe and environs traversed by the aerogravity sheet 312 are underlain by a thick Precambrian basement complex, having varying densities of 2.67g/cm^3 and 2.76g/cm^3. Severe erosion as a result of natural and anthropogenic factors has resulted in the exposure of basement complex as extrusions (surface rocks) at various locations particularly at extremes of profiles 1, 2 and 3. The huge basement complex of the study area is overlaid with sediments of various types and densities, ranging from sandstone, clay, shale, silt and laterite. The NW extreme and SE wing around Obowo, Umuahia and environs are predominated by low-density materials. This is obvious with the negative gravity signatures observed in these places. Materials with the highest densities in the study area are found at the NE axis around places such as ihube, Okigwe, the southern part of isuochi and their environs.

5.0 References

Alsadi, H.N. and Baban, E.N. (2014). Introduction to gravity exploration method – First Edition. *Paiwand press*. 203 pp.

Anyadiegwu, F. C., Aigbogun, C. O. & Eze, M. O (2021). subsurface characterization based on densities, heat sources and thickness of sediments obtained from inverse modelling of gravity data. *International Journal of Geo-informatics and Geological Science*, 8, 2, pp. 53-66.

Araffa, S.A.S., El-bohoty M., Heleika M.A., Mekkawi M., Ismail E., Khalil A. & EL-Razek E.M.A. (2018). Implementation of magnetic and gravity methods to delineate the subsurface structural features of the basement complex in central Sinai area, Egypt, *NRIAG Journal of Astronomy and Geophysics*, 7:1, 162-174.

Aspler, L.B., Pilkington, M., and Miles, W.F., (2003). Interpretations of Precambrian basement based on recent aeromagnetic data, Mackenzie Valley, Northwest Territories; *Geological Survey of Canada, Current Research.* C2, 11 p

Igboekwe, M.U., Agada, I.O. & Amos-Uhegbu, C (2021). Investigation of dumpsite leachate using electrical resistivity tomography at Umueze-Ibeku, Umuahia, South-Eastern Nigeria.*Journal of Scientific and Engineering Research*, 6, 1, pp. 71-80.

Lowrie, W. (2007). *Fundamentals of geophysics*- Second Edition.*Cambridge University Press*, 381 pp

Omosanya, K. O., Mosuro, G. O., Laniyan, T. A.& Ogunleye, D (2012). Prediction of gravity anomaly from calculated densities of rocks.*Pelagia Research Library - Advances in Applied Science Research*, 3, 4, pp 2059-2068

Onyewuchi, R. A. & Ugwu, S. A (2017). Geological interpretation of the high resolution aeromagnetic data over

Okigwe-Udi area, Anambra Basin, Nigeria, using 3-D Euler deconvolution and 2-Ds spectral inversion methods.*Journal of Geography, Environment and Earth Science International* 10, 1, pp 1-22

Pal, S.K., Bhattacharya, A.K. & Majumdar, T.J (2006). Geological interpretation from Bouguer gravity data over the Singhbhum-Orissa craton and its surroundings: A GIS approach. *J. Ind. Geophysics. Union* 10,4, pp.313-325.

Reynolds J.M. (1997) An introduction to applied and environmental geophysics. *John Wiley & Sons Publisher*

6.0 Acknowledgement

Many thanks to Mrs. Joy Ezinne Agada for her financial contribution and being available to meticulously proof read this work.

Consent for publication

Not Applicable.

Availability of data and materials

The publisher has the right to make the data public.

Competing interests

The authors declared no conflict of interest.

Funding

There is no source of external funding.

Authors' contribution.

This work was carried out in collaboration by all authors.