Faculty of Natural and Applied Sciences Journal of Scientific Innovations
Print ISSN: 2814-0877 e-ISSN: 2814-0923
www.fnasjournals.com
Volume 4; Issue 1; March 2023; Page No. 198-210.

APPLICATION OF GRAVITY METHOD IN DETERMINATION OF HYDROCARBON POTENTIALS IN PARTS OF THE ANAMBRA BASIN, SOUTHEASTERN NIGERIA

***Onyeche, I.N., Ombu, R., & Eke, P.O.**
Department of Physics, Ignatius Ajuru University of Education, Port Harcourt, Nigeria.

***Corresponding Author (Email):** ihuomaonyeche@gmail.com

Abstract

The renewed quest to boost Nigeria's dwindling reserves through an aggressive search for oil and gas deposits has re-ignited the need to re-evaluate the hydrocarbon potentials of the Anambra Basin. Aerogravity data are a low-cost geophysical tool deployed in mapping regional basement structures and determination of basement depths and sedimentary thickness in frontier basin exploration. In this study, aerogravity data covering some areas of the Anambra Basin, Southeast Nigeria have been quantitatively interpreted using forward and inverse modelling approaches. The absolute deliverables of the study included the determination of the thickness of the sedimentary basin, density contrasts, and the geological models that will provide details on geological structures capable of retaining hydrocarbon. Before interpretation, the zipped data was extracted and enhanced, gridded, and the regional anomalies were isolated from the residual anomaly by a second-order polynomial fit. Edge detection filters precisely the vertical derivative was applied to the Bouguer gravity grid to locate the edges and contacts of geological structures in the basin. Four profiles denoted as Profiles 1, 2, 3, and 4 were selected on the Bouguer gravity contour map based on the contour shapes for modelling. Results from forward and inverse modelling revealed that faulted anticlines were observed in models 1, 3 and 4, while faulted syncline was observed in model 2. The average estimated sedimentary thickness for profiles 1, 2, 3 and 4 were 5.7 km, 8.4 km, 6.3 km, and 2.7 km, with density contrast of anomalous bodies of 0.18 g/cm^3, 0.48 g/cm^3, 0.84 g/cm^3 and 0.17 g/cm^3 respectively. In terms of hydrocarbon potentials, these depth ranges and density distribution suggest a promising basin. The results of this study can therefore be used as an affordable and useful decision-making tool to precisely map subsurface features and define sedimentary thicknesses for hydrocarbon potential that can be economically beneficial to increase foreign exchange revenues in the state and federal government

Keywords: Anambra Basin, Aerogravity, density contrast, sedimentary thickness.

Introduction

Gravity prospecting is the process of measuring variations in the earth's gravitational field at the surface, whether on the land, sea or in the air. It is a passive method, in the sense that no artificial energy is required to acquire data. The strength of the gravitational field is directly proportional to the mass and the density of subsurface materials. Gravity value changes as objects move from one position on the Earth's surface to another. As a result,

Cite this article as:
Onyeche, I.N., Ombu, R., & Eke, P.O.. (2023). Application of gravity method in determination of hydrocarbon potentials in parts of the Anambra Basin, Southeastern Nigeria. *FNAS Journal of Scientific Innovations*,*4*(1), 198-210.

gravity measurements provide information on the densities of underlying rocks, which can be used to better understand subsurface geology. There is a wide range in density among rock types, and therefore geologists can make inferences about the distribution of strata. The success of this method is dependent on the different bulk densities (mass) of the earth's materials, which cause variations in the measured gravitational field. The depth, geometry, and density that cause the gravity field variations can then be determined using a variety of analytical and computational methods.

Hydrocarbons (gas alone, oil alone or both gas and oil) are usually found in rock bodies in the earth's subsurface. This rock body could be a source rock or reservoir rock. Source rock is a rock that can generate hydrocarbons in large quantities that will lead to accumulated gas and oil for commercial purposes. Reservoir rock is any rock that is porous and permeable enough and could store and transmit fluids (hydrocarbons). Hydrocarbons commonly occur in sedimentary basins and are absent from intervening areas of igneous and metamorphic rocks (Selley & Sonnenberg, 2015). In sedimentary basins, basement faults are important structurally because they can influence and hence determine the overall basin architecture, and tectonic history and control mineralization sites, oil and gas traps and groundwater flow patterns. Gravity methods play an important role in the recognition of sedimentary basins (Ali *et al*., 2014) and structures in which hydrocarbons are entrapped (Tschirhart et al., 2017). This is possible since the densities of different sedimentary rock formations are usually lower than those of the surrounding basement rocks.

The Anambra Basin is an inland sedimentary basin and is one of Nigeria's most promising hydrocarbon-producing fields (Obaje, 2009). It is a 300-kilometre northeast–southwest-trending syncline at the southwestern end of the Benue Trough in southeastern Nigeria, formed by tectonic upheavals within the trough during the Santonian period. The basin is also considered a frontier basin by Dim *et al*. (2019) because of the difficulties in interpreting stratigraphy and structure due to the lack of subsurface data. Only a few discoveries have been made in the basin even though more than 40 exploratory wells have been drilled (Ukaonu et al., 2017). Nonetheless, the Anambra Basin's hydrocarbon and coal potential is being focused on due to discoveries and oil seeps that have established an active petroleum system. As of 2019, the basin's oil production was estimated to be approximately 10,000 barrels per day (Sunnewsonline, 2019).

Mapping subsurface geological structures in which hydrocarbons are entrapped (Khazri and Gabtni, 2018; Dilalos *et al*., 2019) is another important role gravity methods play. This is possible since the densities of different sedimentary rock formations are usually lower than those of the surrounding basement rocks. Therefore, the reconnaissance gravity survey provides useful information as to whether the sedimentary thickness beneath the earth’s subsurface is sufficiently thick enough to justify further geophysical investigations. The present study represents a significant attempt at determining the depth to basement, structural types, sedimentary thickness, and hydrocarbon potentials, using gravity data analysis and interpretation from a survey in the Anambra Basin, South-eastern Nigeria.

Location and Geology of the Study Area

The study area is the Anambra basin which is located approximately between longitudes 6 º 30' E and 8º 00'E and latitudes 5º00'N and 8º00'N. The basin covers an area of more than 30, 000 km^2 (Babatunde, 2010) and contains

Cite this article as:
Onyeche, I.N., Ombu, R., & Eke, P.O.. (2023). Application of gravity method in determination of hydrocarbon potentials in parts of the Anambra Basin, Southeastern Nigeria. *FNAS Journal of Scientific Innovations*,*4*(1), 198-210.

more than 2 km of Cretaceous (i.e., post-deformational sediments of Campanian-Maastrichtian to Eocene ages) marine, paralic, and deltaic facies sediments in out-cropping sections that extend into adjacent tectonic basins such as the Abakiliki Trough, the Afikpo Syncline, and the Calabar Flank (Abubakar, 2014). The Anambra Basin is situated at the southwestern extremity of the Benue Trough. It is bounded to the west by the Precambrian basement complex rocks of western Nigeria, and to the east by the Abakaliki Anticlinorium (Obaje, 2009; Onyekuru et al., 2010). The north and south boundaries of the Anambra Basin are defined by the Niger hinge line and the Niger Delta hinge line, respectively (Odunze & Obi, 2013). Ekine and Onuoha (2008) recognize the northern boundary of the basin to coincide with the limit of exposure of the Maastrichtian sediments and the southern boundary to be at Onitsha, which is the northernmost limit of the Tertiary-Present Niger Delta Basin (Figure 1).

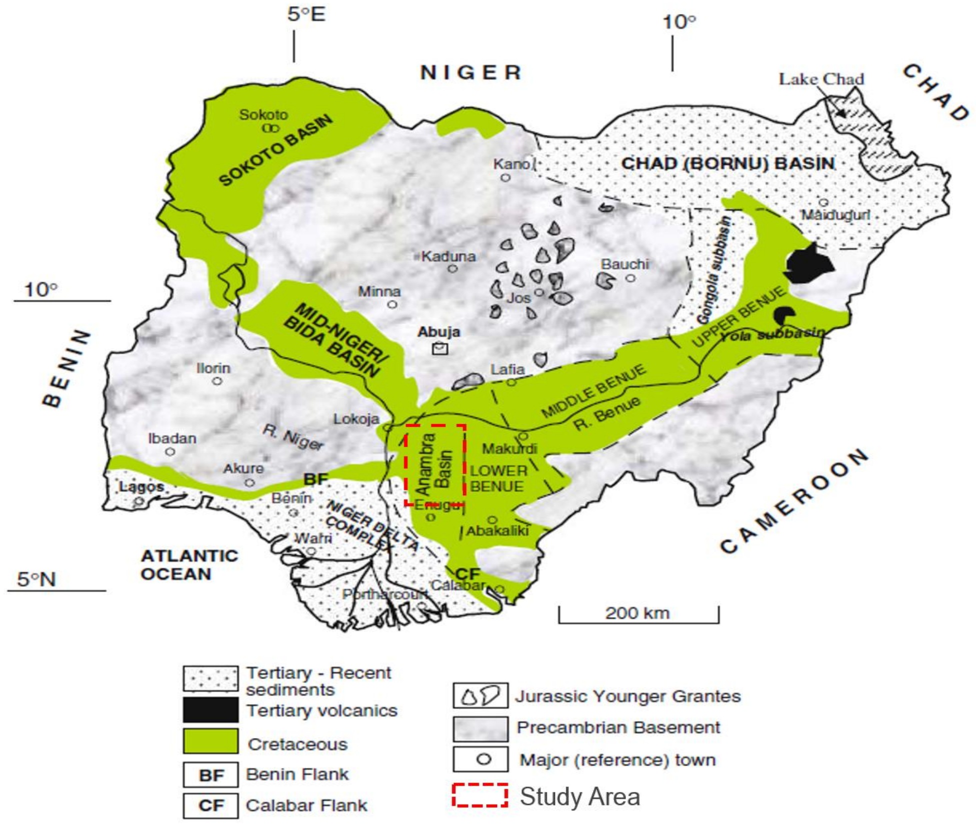

Figure 1. Location and Geological map of Nigeria showing the Anambra Basin (Obaje, 2009).

Theoretical Background

The basis of the gravity survey method is Newton's Law of Gravitation, which states that the force of attraction $\vec{F}$ between two masses m_1 and m_2, whose dimensions are small concerning distance, r, between them is given by the formula in equation 1.

$$\vec{F} = -\hat{e}_r \frac{Gm_1m_2}{r^2} \qquad (1)$$

where $\hat{e}_r$ is a unit vector in the direction of the position vector r of mass m_2 concerning mass m_1 and $r = |\vec{r}|$ G is the Gravitational Constant ($6.67 \times 10^{-11} m^3 kg^{-1} s^{-2}$)

Consider the gravitational attraction of a spherical, non-rotating, homogeneous Earth of mass M and radius R on a small mass m on its surface. It is relatively simple to show that the mass of a sphere acts as though it were concentrated at the centre of the sphere and by substitution in equation 1 we have

$$F = \frac{GM}{R^2} m = mg \qquad (2)$$

Force is related to mass by acceleration and the term $g = GM/R^2$ is known as gravitational acceleration or, simply, gravity. The weight of the mass is given by mg. On such an Earth, gravity would be constant. However, the Earth's ellipsoidal shape, rotation, irregular surface relief and internal mass distribution cause gravity to vary over its surface.

Materials and Methods

The digitized Bouguer gravity data used in this research work was obtained from the gravity database of Bureau Gravimetrique International (BGI) covering areas in the Anambra Basin. The data in zipped format were first converted to text format and sorted out into the required longitudes and latitudes of the study area. The methods for the data analysis and interpretation included data enhancement, production of base maps, contouring, modelling, and depth estimation. Data enhancement and processing were done to make the data usable and ready for interpretation. Data enhancement routines performed were gridding and polynomial fitting. The basement of the Basin map was produced before contouring and modelling. Depth estimation of the source of anomalies was obtained using the forward and inverse modelling methods (Biswas et al., 2017). The first step in the interpretation was the gridding of the potential field data. This was to ensure that the image processing and interpretation were converted to an evenly spaced two-dimensional (2D) grid (Obiora et al., 2016). Gridding of data was achieved using a minimum curvature gridding algorithm. To facilitate the application of Fourier transform (FT)-based techniques and to minimize distortions of the gravity field that is a normal consequence of sampling at grid points only, the gridded maps were projected onto the Cartesian coordinate system using Universal Transverse Mercator (UTM) projection parameters of the study area (i.e., Zone 32 UTM) with WGS84 datum. Regional-residual separation was done to remove the regional anomalies from the Bouguer gravity anomaly to obtain the residual anomalies. The residual component is due to relatively local near-surface masses while the regional component is that component of the total field arising from larger and deeper structures beneath the earth's surface. The regional-

Cite this article as:
Onyeche, I.N., Ombu, R., & Eke, P.O.. (2023). Application of gravity method in determination of hydrocarbon potentials in parts of the Anambra Basin, Southeastern Nigeria. *FNAS Journal of Scientific Innovations*,*4*(1), 198-210.

residual separation of the third-order polynomial fitting provided the best visual fit for this work. The regional field g_R obtained from the third polynomial represented by equation 3

$$g_R = a_0 + a_1x + a_2x^2 + a_3x^3 .... + a_nx^n \qquad 3$$

where n is the order of the polynomial being used to approximate the regional field. The coefficients are evaluated using the principles of least squares and the trends of different orders (n) are computed. The first vertical derivative filter was applied to the enhanced data to image the causative structures using equation 4 as applied in the Oasis Montaj Software.

$$FVD = -\frac{\partial A}{\partial Z} \qquad 4$$

Forward and inverse modelling techniques to obtain numerical estimates of the depth and dimensions of the sources of anomalies based on Euler equations (Biswas et al., 2017) were applied. This was achieved practically with the Potent Q 3D tool of the Oasis Montaj TM software. Four regions or points were selected based on the contour cluster configuration for modelling.

Results

Contour Map of the Anambra Basin

The contour map of the region (Fig. 2) at intervals of 5mgals reveals the subsurface mass distribution and tending of the subsurface structures.

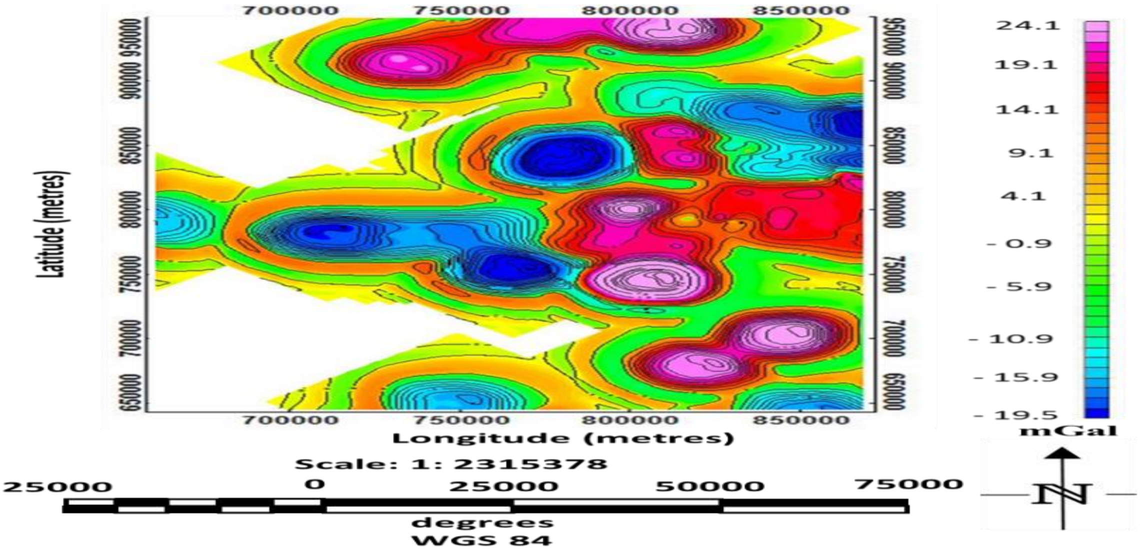

Figure 2: Contour map of the Anambra Basin

Forward and Inverse Modeling

The points marked 1,2, 3 and 4 were choosing for the modeling. These regions were choosing based on the contour clusting which will probably give the expected results. The modelled results are shown in figures 4, 5, 6, and 7. The model types and results are shown in Table 1.

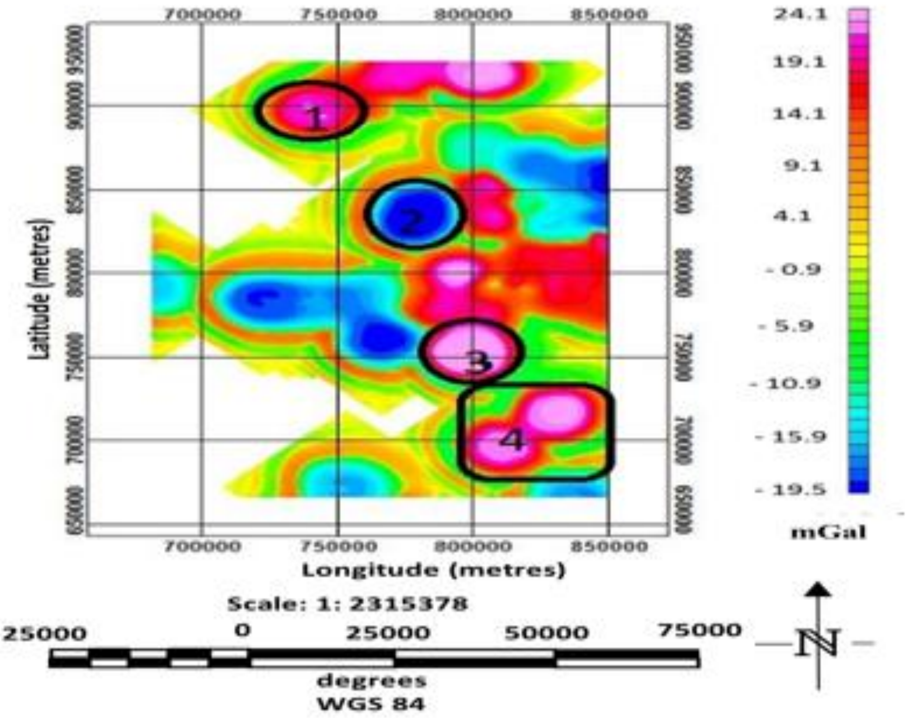

Figure 3. Bouguer gravity grid indicating the four points that were modeled.

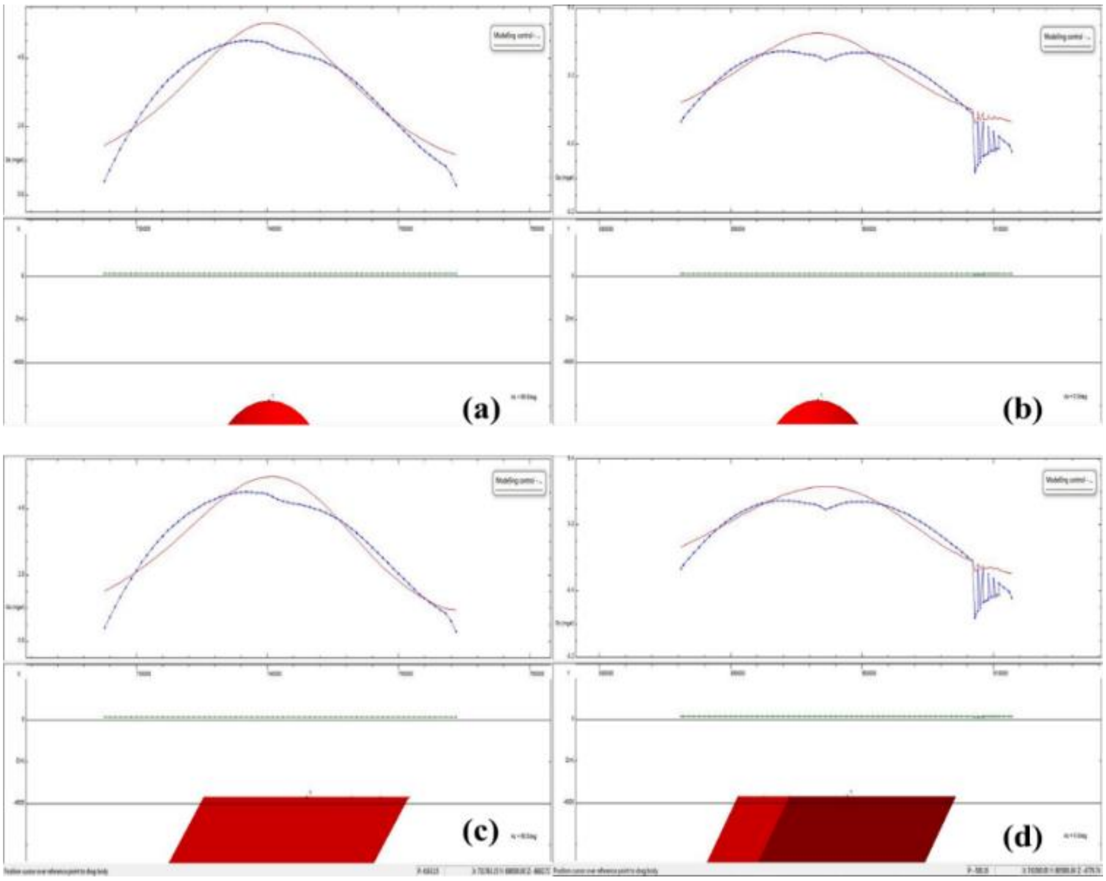

Figure 4: Model result of point 1 (a) Using a sphere model at 90° (b) Using a sphere model at 0° (c) Using a dyke model at 90° (d) using a dyke model at 0°

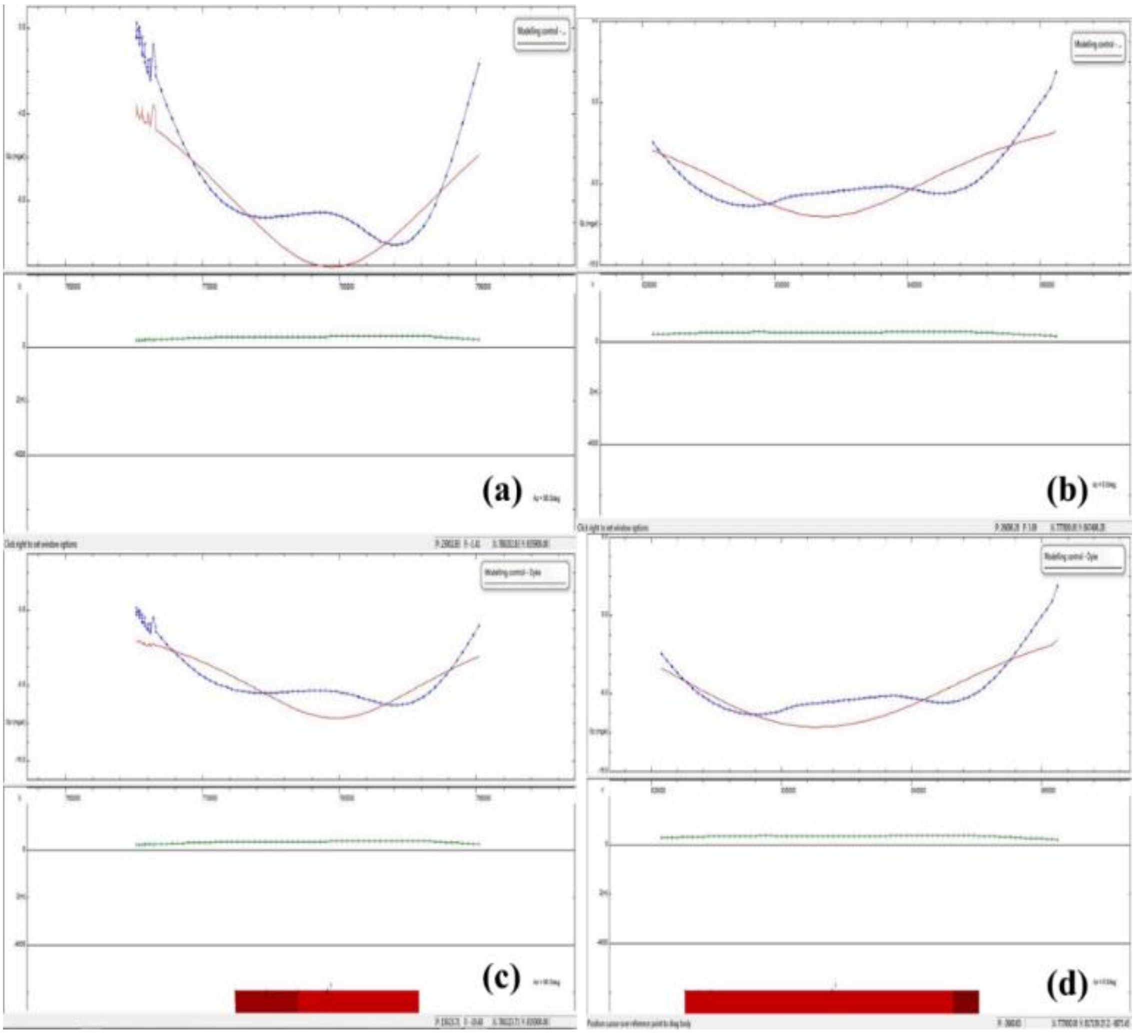

Figure 5: Model result of point 2 (a) Using a sphere model at 90°. (b) Using a sphere model at 0° (c) Using a dyke model at 90° (d) using a dyke model at 0°.

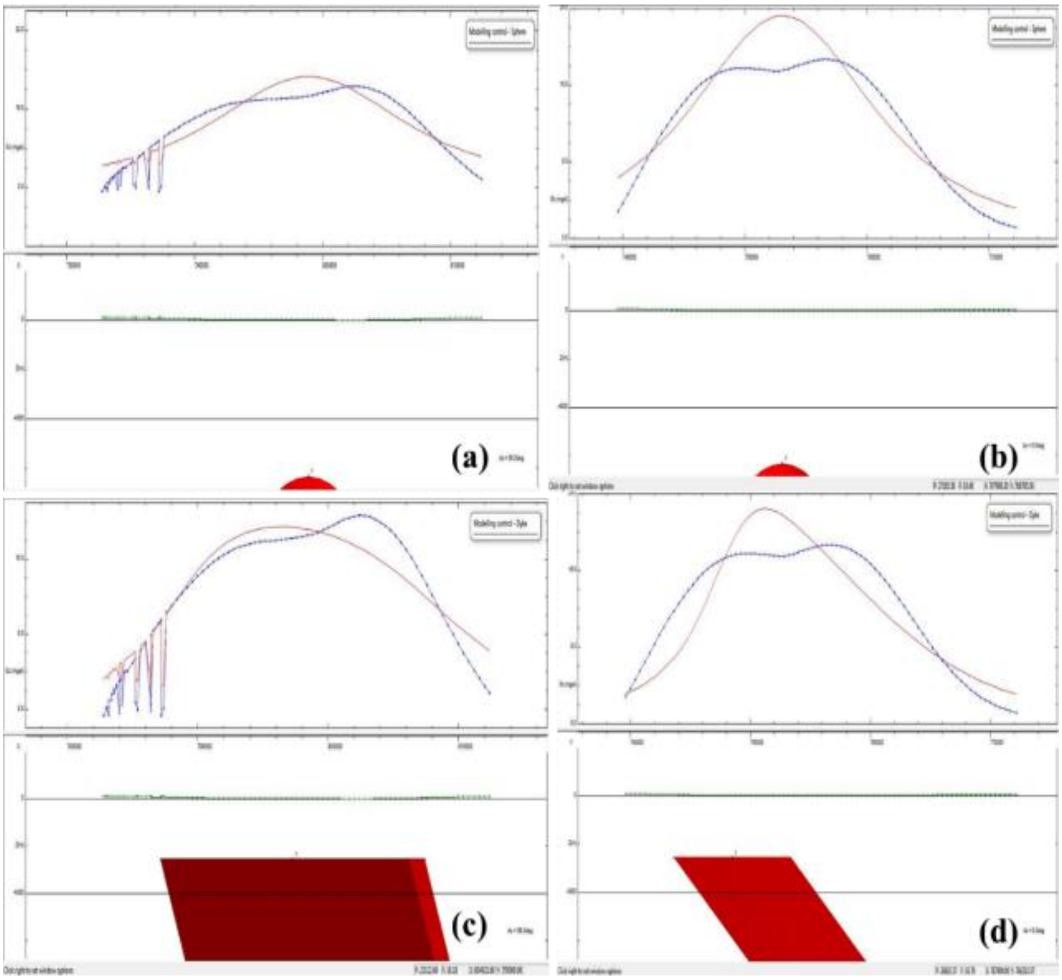

Figure 6: Model result of point 3 (a) Using a sphere model at 90°. (b) Using a sphere model at 0° (c) Using a dyke model at 90° (d) using a dyke model at 0°.

Cite this article as:
Onyeche, I.N., Ombu, R., & Eke, P.O.. (2023). Application of gravity method in determination of hydrocarbon potentials in parts of the Anambra Basin, Southeastern Nigeria. *FNAS Journal of Scientific Innovations*,*4*(1), 198-210.

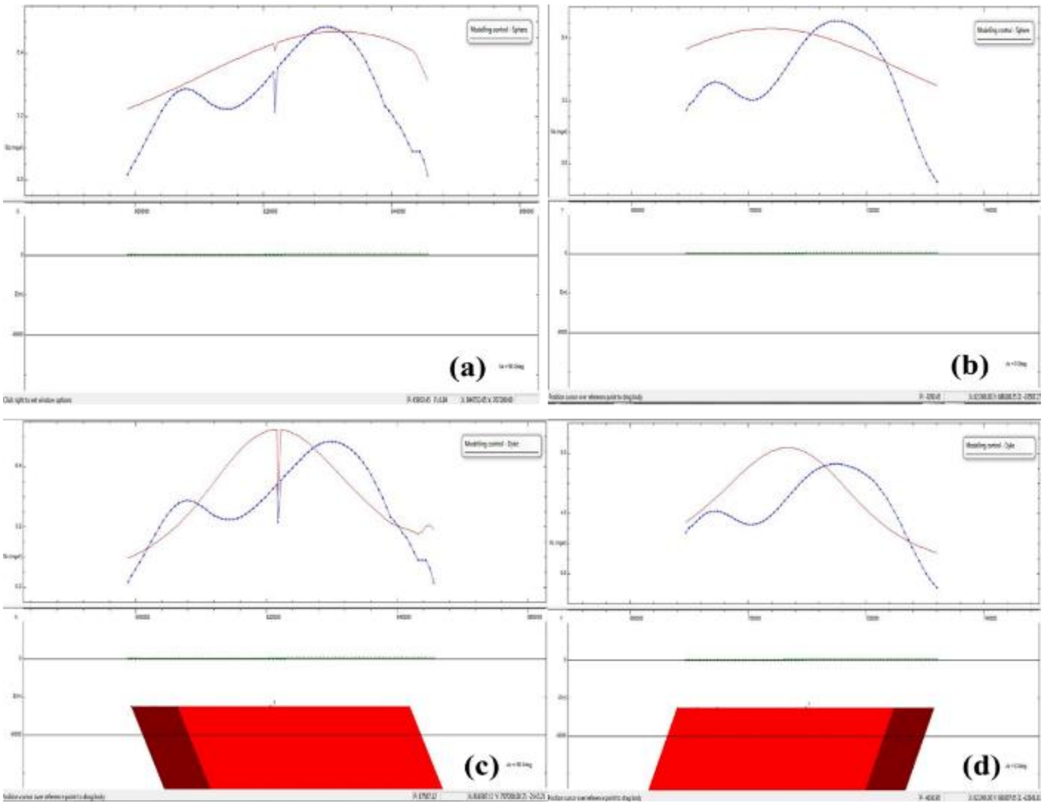

Figure 7: Model result of point 4 (a) Using a sphere model at 90°. (b) Using a sphere model at 0° (c) Using a dyke model at 90° (d) using a dyke model at 0°

Table 1: Model results for selected points

Model	Model Shape	Depth to Anomalous bodies (m)	Density Contrast of the formations (g/cm^3)	Root Mean Square Error	Possible cause of anomaly
1	Sphere	5772	0.186	0.552	Anticline \ Faulted
	Dyke	3701	0.083	0.568	Anticline
2	Sphere	8497	0.487	2.009	Syncline \ Faulted
	Dyke	4978	0.258	1.670	Syncline
3	Sphere	6358	0.848	2.356	Faulted Anticline
	Dyke	2556	0.424	8.546	
4	Sphere	2723	0.176	2.595	Faulted Anticline
	Dyke	5015	0.073	2.065	

Discussion

The Bouguer contour map shows the topography of the subsurface as derived from the gravity data. This translates to the structural trends in the region and also mass distribution within the area. From the map, the colour legend bar in Figures 2 and 3 has several colours. The pink colour indicates an area with gravity highs, the green and yellow colour, indicates areas with intermediate gravity values while the blue colours show areas with gravity lows. Negative gravity anomaly (−19.5 mGal) seen as circular closures around the central parts of the field indicate the presence of subsurface denser rocks. The north and south parts of the field have circular closures with very low gravity anomalies.

The contour shapes also determined the points selected for modelling. Points 1,2,3, and 4 as shown in Figures 4 – 7 reveal the following selected point 1 is located between 725, 000 and 760, 000 meters easting and 880, 000 and 920, 000 meters northing. Point 2 is located between 760, 000 and 794, 000 m east of the equator and 820,000 and 857,000 m north of the equator. Profile 3 is situated between 780,000 and 820,000 m east and 740,000 and 775,000 m north. Profile 4 is located between 689,000 and 740,000 meters east of the equator and between 795,000 and 850,000 meters north of the equator.

The selected points for modelling were analysed by forward and inverse modelling using both spherical and dyke models in 2D using the Oasis Montaj software package. Point 1 reveals that the sphere model gave a better result because the root mean square error of 0.552 is less than 0.568 for a dyke model. Thus we can infer that the depth to anomalies body in that region is 5772m which also represents the sediment thickness. The structures identified were anticlines and faults. This sediment thickness and structural type are conducive to hydrocarbon reservoirs. Furthermore, the density contrast of 0.083 gm-3 makes the sediment an ideal host for hydrocarbons.

Profile 2 lies approximately between 760, 000 and 794, 000 m Easting and 820,000 and 857,000 m Northing on the residual Bouguer anomaly base map. The Oasis Montaj software was used to create 2D forward models of the sphere and dyke. The anomalous body was given a depth of 8497 meters by the sphere model. According to studies on gravity interpretation, the spherical profile may represent a syncline. The density of the anomalous body was discovered to be 0.487g/cm3, which is thought to be hydrocarbons. Petroleum is associated with densities of between 0.5 and 0.9 g/cm3. Figure 4a gravity signature implies that the anomalous body is denser than the nearby bedrock. The dyke model in Figure 4b similarly showed a very low density of 0.258g/cm3, which was assumed to be likely oil. The anomalous body is 4978 meters deep, 4978 meters wide, and it is thought to be a faulted syncline. The fact that the root mean square in both instances is low, at 2.009 and 1.670, respectively, indicates that the modelling results are valid. On the residual Bouguer anomaly base map, Profile 3 is located approximately between 780,000 and 820,000 m Easting and 740,000 and 775,000 m Northing. The anomalous bodies in the sphere and dyke models have depths of 6358 m and 2556 m, respectively. The density of the anomalous body is between 0.848 and 0.424 g/cm3, which is within the range of hydrocarbon density. Both models have a faulted anticline as the inferred structure. The values of the root mean square are, respectively, 2.356 and 8.546, showing a precise forward model. Finally, the coordinates of Profile 4 lie approximately between 689, 000 and 740, 000 m Easting and 795,000 and 850,000 m Northing on the residual Bouguer anomaly base map. The depths of the anomalous bodies in the sphere and dyke models were between 2723 m and 5015 m. The density of the anomalous body was 0.176 and 0.073g/cm3 respectively which falls under the range of density of gas-saturated sands. The inferred structure is predicted to be a faulted anticline for both cases. The root means square values are respectively 2.595 and 2.065 indicating an accurate forward model.

Conclusion

In this study, a thorough analysis and interpretation of high-resolution aerogravity data for the Nigerian Anambra Basin to determine the thickness of the sedimentary basin, density contrasts, and geological models that will provide information about the variety of geological structures have been successfully carried out. From the 2D forward and inverse models, it was observed that the sediment-basement interface has a rugged topography. The models showed faulted anticlines and syncline structures. The estimated depth from forward and inverse modelling for profiles 1, 2, 3 and 4 were 5.7 km, 8.4 km, 6.3 km, and 2.7 km, with respective density values of 0.18 g/cm^3, 0.48 g/cm^3, 0.84 g/cm^3 and 0.17 g/cm^3. These depth ranges, density values and distribution of anomalies in the area favour a promising basin in terms of hydrocarbon potential. The depth range obtained in this work agrees with the depth range for hydrocarbon maturation and generation. It also agrees with works carried out by other researchers and is consistent with the depth of the basement of the survey area. The depth ranges agree with the works of Olagundoye et al., 2021; Abdullahi and Kumar, 2021. The mini basins are adjudged to be highly prospective zones for hydrocarbon occurrence due to the accumulation of considerably thick sediments in them.

References

Abdullahi, M., & Kumar, R. (2021). Basement and structure near the Southwestern Margin of the lower Benue trough between, and including, the Anambra Basin and Afikpo Syncline, as derived from aeromagnetic and gravity data. *Pure and Applied Geophysics*, 178(10), 3953-3970.

Abubakar, A. M. (2014). *Petroleum potentials of the Benue Trough and Anambra Basin: a regional synthesis.* Natural Resources, 5, 25–58.

Ali, M.Y., Watts, A.B. & Farid, A. (2014). Gravity anomalies of the United Arab Emirates: implications for basement structures and infra-Cambrian salt distribution. *GeoArabia* 19(1), 85–112.

Babatunde, O. L. (2010). The main oil source formations of the Anambra Basin, Southeastern Nigeria, Nigeria. *Presented at the AAPG International Convention and Exhibition, Calgary, Alberta, Canada.*

Biswas, A., Parija, M. P., & Kumar, S. (2017). Global nonlinear optimization for the interpretation of source parameters from total gradient of gravity and magnetic anomalies caused by thin dyke. *Annals of geophysics*, 60(2), G0218, 1-17.

Dilalos, S., Alexopoulos, J.D., & Lozios, S., (2019). New insights on subsurface geological and tectonic structure of the Athens basin (Greece), derived from urban gravity measurements. *Journal Application of Geophysics* 167, 73–105.

Dim, C. I. P., A. W. Mode, & I. C. Okwara, (2019). Signatures of key petroleum system elements: Outcrop examples from the Anambra Basin, south-eastern Nigeria. *Journal of Petroleum Exploration and Production Technology*, 9, 1615–1631.

Ekine, A. S., & Onuoha M. K. (2008). *Burial History Analysis and Subsidence in the Anambra Basin, Nigeria.* Department of Physics University of Port Harcourt, Nigeria; Department of Geology University of Nigeria, Nsukka, Nigeria. www.ajol.info.

Khazri, D., & Gabtni, H., (2018). Geophysical methods integration for deep aquifer reservoir characterization and modelling (Sidi Bouzid basin, central Tunisia). *Journal of Africa. Earth Science.* 138, 289–308.

Obaje, N.G., (2009), *Geology and Mineral Resources of Nigeria: Lecture Notes in Earth Sciences*, Springer.

Obiora, D. N., Ossai, M. N. Okeke, F. N. & Oha, A. I. (2016) Interpretation of airborne geophysical data of Nsukka area, Southeastern Nigeria: *Journal of the Geological Society of India*, 88, 654–667.

Odunze, S.O., & Obi, G.C. (2013). Sedimentology and sequence stratigraphy of the Nkporo Group (Campanian–Maastrichtian), Anambra Basin, Nigeria. *Journal of Paleogeography*. 2(2), 192–208.

Olagundoye, O. O., Okereke, C. S., Edet, A. E., Obi, D. & Ukpong, A. (2021), Depth to magnetic basement in the Anambra Basin, Benue Trough of Nigeria from aeromagnetic data: A prelude for hydrocarbon exploration, *Interpretation 9*: 11-26.

Onyekuru S.O., Nwankwor, G.I & Akaolisa, C.Z. (2010). Chemical Characteristics of Groundwater Systems in the Southern Anambra Basin, Nigeria. *Journal of Applied Sciences Research*, 6(12), 2164-2172

Selley, R.C., & Sonnenberg, S.A. (2015). *Elements of Petroleum Geology*. 3rd Edition, Elsevier, Amsterdam, 507.

Sunnewsonline, 2019, NNPC, Anambra Basin and the search for oil, https://www.sunnewsonline.com/nnpcanambra- basin-and-the-search-for-oil, accessed 8 April 2021.

Tschirhart, V., Jefferson C. W. and Morris, W.A. (2017) Basement geology beneath the northeast Thelon Basin, Nunavut: insights from integrating new gravity, magnetic and geological data. *Geophysical Prospect.* 65(2), 617–636.

Ukaonu, C. E., S. O. Onyekuru, & D. O. Ikoro, 2017, Facies architecture and reservoir properties of Campanian-Maastrichtian Nkporo Formation in the Anambra Basin, Nigeria: *Scientific Research Journal*, 5, 1–11.

Cite this article as:
Onyeche, I.N., Ombu, R., & Eke, P.O.. (2023). Application of gravity method in determination of hydrocarbon potentials in parts of the Anambra Basin, Southeastern Nigeria. *FNAS Journal of Scientific Innovations*,*4*(1), 198-210.