European Journal of Science, Innovation and Technology

ISSN 2786-4936

Vol. 2 No. 5 (2022)

Subsurface Structural Features of Nasarawa State, Nigeria, from Aerogravity Data

Eke, Peter Ogochuku [1*], Okafor, Obianuju Lynda [2], Ziriki, Godwill [3]
[1]Associate Professor, Ignatius Ajuru University of Education, Port Harcourt, Nigeria
[2]Postgraduate Student, Ignatius Ajuru University of Education, Port Harcourt, Nigeria
[3]Senior Lecturer, Department of Physics, Bayelsa Medical University, Yenaoga, Nigeria

Abstract. Subsurface structural and content information of the earth are usually needed to evaluate the geology and explore the natural minerals underground. With no direct access to the details of the subsurface, geophysical methods provide the needed data. In this study, extracted aerogravity data from a pool of data collected by Bureau Gravimétrique International (BGI) has been interpreted for subsurface information on sedimentary thickness; structural types and basement depths of Nasarawa state, Nigeria. This was achieved with the aid of Oasis Montaj software using the principles of data enhancement, separation of regional and residual effects, gridding, contouring, Euler depth estimation and forward/inverse modelling. The results indicate subsurface formations with high mass density in the central and northern parts of the state and low mass density formations in the northwestern and southwestern parts of the state. The structures trend mostly in east-west, northeast-southwest, north-south and northwest-southeast directions. Models reveal syncline and anticline structures with strike-slip faults at varying depths from 4141 m. The depth estimate results show sediment depths of 15 m and above which also corresponds to the basement depth variations in the state. The structures and sediment depths in some regions make them possible hydrocarbon sources/reservoirs, just as in the adjacent Bida Basin and hence it is recommended that geophysical prospecting for hydrocarbons should be carried out in these areas.

Key words: subsurface, sedimentary thickness, basement, syncline and anticline structures

Introduction

The Earth's subsurface is a host to most natural minerals that are of immense benefit to mankind. These subsurface structures and contents can only be revealed or seen and explored with the aid of geophysical studies utilizing different geophysical survey methods. Geophysical methods (Reynolds, 2011) measure certain physical earth parameters and the data is interpreted to obtain details of the subsurface, mostly, content, structure and sediment/basement thickness and depths. The gravity method, which is a potential method of geophysical exploration, measures the minute variations in the Earth's gravitational acceleration. It is a passive, non-invasive and non-destructive remote sensing method that is cheap and can be used in remote terrains including highly populated areas (Eke et al., 2016). The task is to find the subsurface mass distribution in the gravitational field as recorded on the Earth's surface by the measuring instrument, the gravimeter (Robinson & Coruh, 2018). The method is a utility method for several applications that include; subsurface regional geological structural studies, search for ground water in deep sedimentary basins and groundwater characterization, search for minerals and archeological imaging (Eke et al., 2016; Ali & Whitely, 1981; Handayani et al., 2018; Amoah, 2018; Mariita, 2010).

Exploration and exploitation of minerals offers a range of benefits to mankind as these minerals can be used for man's sustenance. Nigeria is blessed with a host of minerals (Obaje, 2009) which except from its local uses provides employment opportunities and revenue for the country. Nasarawa State, Nigeria is endowed with mineral resources (Alexander et al., 2015) which have not been fully exploited. Except from hydrocarbon which is predominantly

*Corresponding Author

explored in the Niger delta, other parts of the country also have minerals including the hydrocarbon that has not been fully exploited. Nasarawa state has sedimentary basins with potentials for hydrocarbon exploration as in the Bida Basin (Adeleye, 1974; Adewumi & Salako, 2017). Hence there is the need for more information on the geology of the state to encourage the exploitation of these abundant minerals.

Nasarawa State, Nigeria (Figure 1) lies between latitudes 7^{o} 45' N and 9o 25' of the equator and between longitude 7^{o} and 9^{o} 37' of the Greenwich meridian with total land area of about 27, 000 square kilometers.

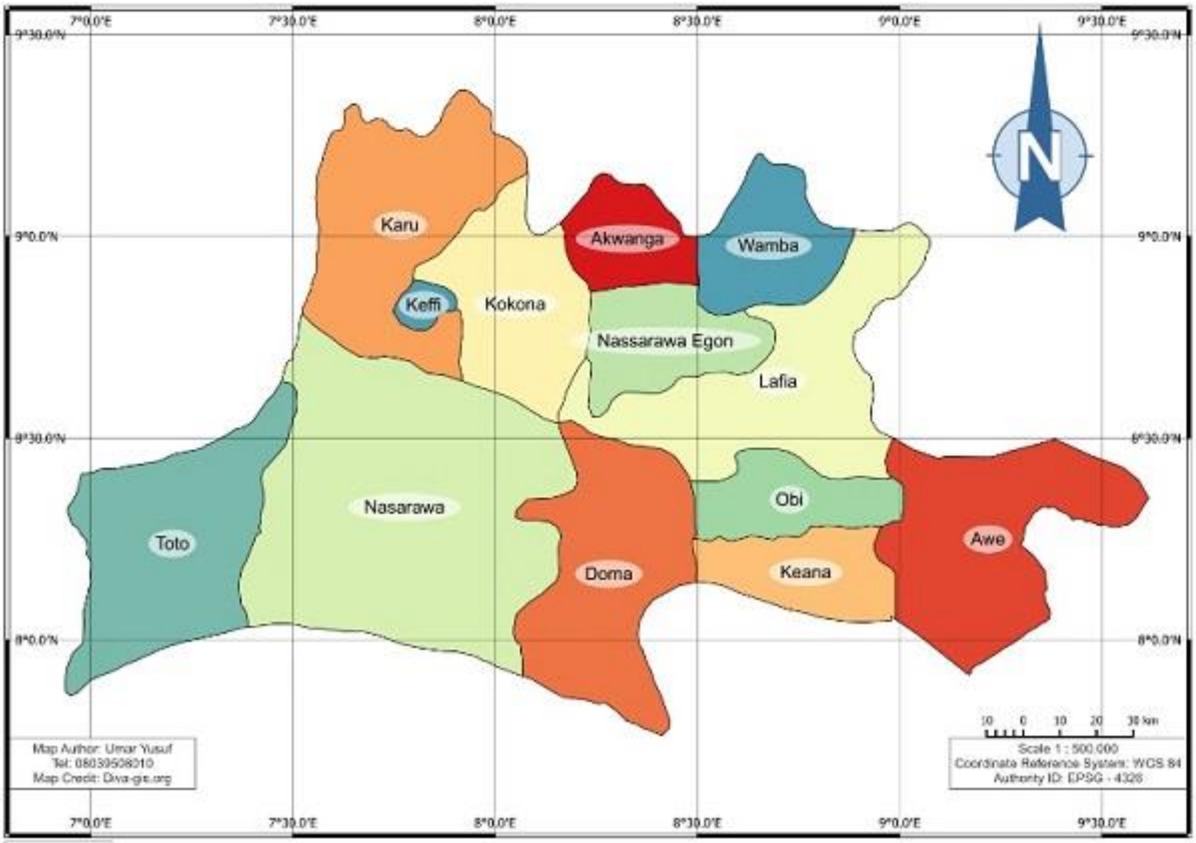

Figure 1: Map of Nasarawa State, Nigeria (Google maps, 2022)

The state is in the tropical climate zone with surface physical features that are partly mountainous, rocky and undulating. Some parts of the state are plain terrains with the river Benue having its tributaries running through most parts of the state. Obaje (2009), Obaje et al. (2011) and Idzi et al. (2013) explain that the state lies in the Bida basin of Nigeria which is one of the seven inland basins in the country containing sediment-fills of Cretaceous to Tertiary ages as found in the other basins of; Niger Delta, Anambra, Benue Trough, Chad, Sokoto and the Dahomey (Benin Embayment). Cretaceous sediments of sandstones, siltstones, inter-bedded clays abound in the state containing natural minerals of coal, barytes, lead, zinc, precious metals and gemstones (nasarawastate.gov.ng, 2022).

Materials and Methods

Measured variations of the Earth's gravitational field values on the surface can be caused by lateral variation of subsurface rock-densities. Thus, a given rock body whose density is different from its surrounding medium (geological anomaly) produces a corresponding disturbance, gravity anomaly, in the Earth's gravity field (Alsadi & Baban, 2014). The form and amplitude of the created anomaly depend on the subsurface geological anomaly and on regional structures such as regional dipping strata, sedimentary basins, geosynclines and mountain roots (Dobrine, 2010). From the Newton's law of universal gravitation (Kearey et al., 2013) the magnitude of the gravitational force, *F*, between the two masses m_1 and m_2, separated by a distance of *r*, in a field of gravitational constant, G, is

$$F = G\frac{m_1 m_2}{r^2} \tag{1}$$

This gives the force per unit mass, the gravitational acceleration, g, as,

$$g = G\frac{m}{r^2} \tag{2}$$

Which for a particle-mass *Δm,* is

$$\Delta g = G\frac{\Delta m}{r^2} \tag{3}$$

In a field work, the measured acceleration is usually the vertical component, which for a continuous body of mass *dm* at a depth *z*, is (Lowrie, 2017),

$$g_z = G\int_v \frac{dm}{r^2}\cos\theta \tag{4}$$

Measured data along planed profiles, sample variations in subsurface mass distribution. The airborne gravity data for this work is a secondary data extracted from the pool of data collected by Bureau Gravimétrique International (BGI) that collect data on a world-wide basis for purposes of subsurface residual and regional interpretations (http://bgi.cnes.fr, 2022).

The extracted data was processed with the aid of Oasis Montaj software by first improving the data using a first order filtering operation and then separating the regional and residual anomaly (Hakim & Chokri, 2017) using the principle of equation 5:

$$g_r = a_o + a_1 x + a_2 x^2 + ... + a_n x^n \tag{5}$$

The residual data was gridded and used to produce a base and Bouguer gravity map of the state. This gave the trending and Bouguer gravity values/mass distribution within the state. Selected portions of the enhanced Bouguer base map was modelled for structural and depth information, using the potent menu of inverse and forward modelling of the Oasis Montaj software. The modelled points gave structural types/depths information and also a clue of possible potential hydrocarbon sources/reservoirs of the region. The Euler depth principle of

$$(x - x_o)\frac{\partial T}{\partial x} + (y - y_o)\frac{\partial T}{\partial y} + (z - z_o)\frac{\partial T}{\partial z} = \eta(T - B) \tag{6}$$

where ($x_o, y_o,$ and z_o) is the position of the gravity source whose total field T is detected at $x, y,$ and z, with total regional field value B and η (for this case equal to one), the structural index (Ali *et al*., 2013) was applied using the Euler deconvolution menu software for depth information.

Results

The results of the subsurface gravity values depicting subsurface mass distribution of formations and structural trending within the state is shown in Figure 2.

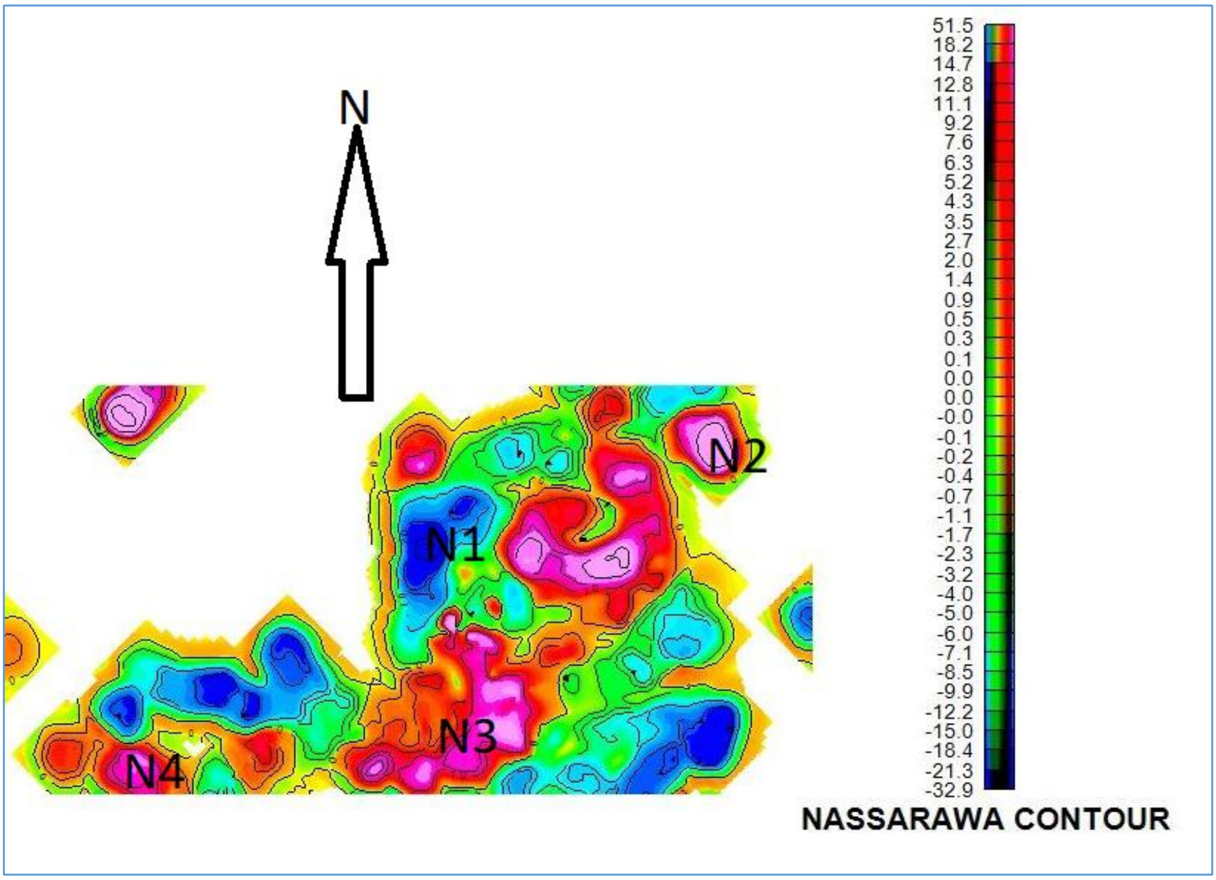

Figure 2: Bouguer gravity, mass distribution and trending of Formations within Nasarawa State, Nigeria

The color legends depicts the Bouguer gravity values distribution and subsequently the subsurface mass distribution/structural trending within the state. Points N1, N2, N3 and N4 are the modelled points using dyke models for depth and structural type information. The model results are shown in Figures 3 to 6.

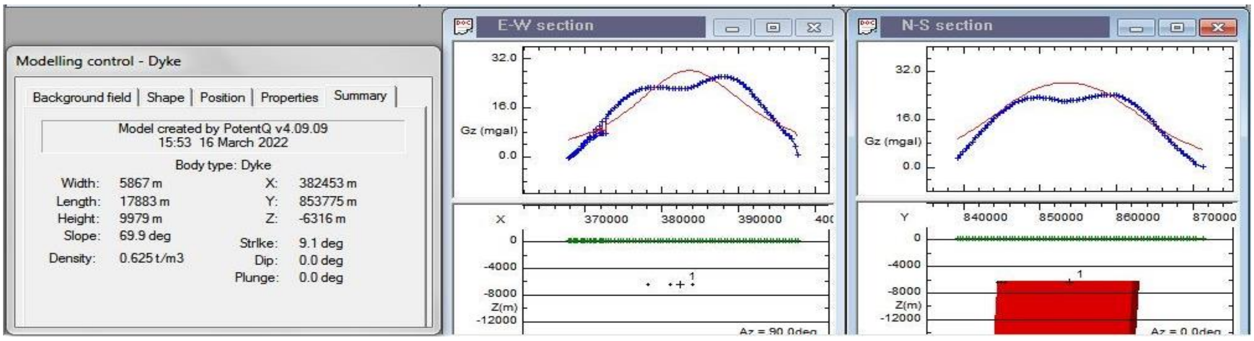

Figure 3: Point N1 modelled as a faulted anticline from a dyke model

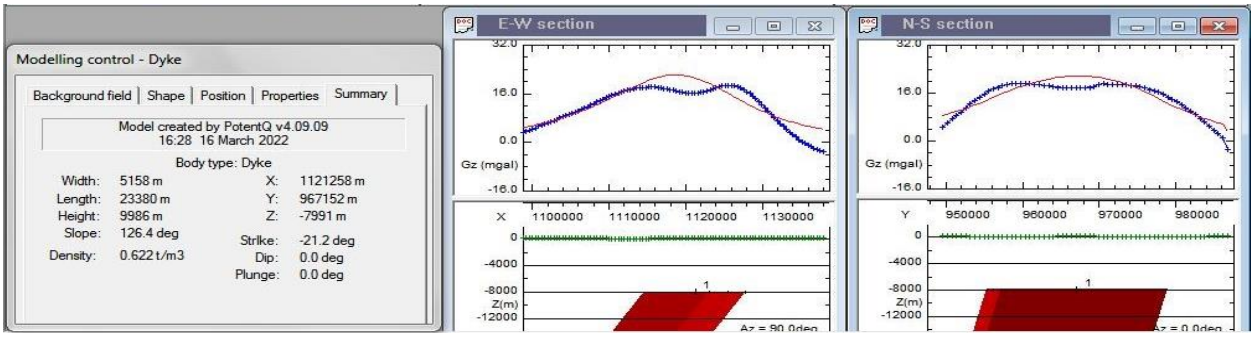

Figure 4: Point N2 modelled as a faulted anticline from a dyke model

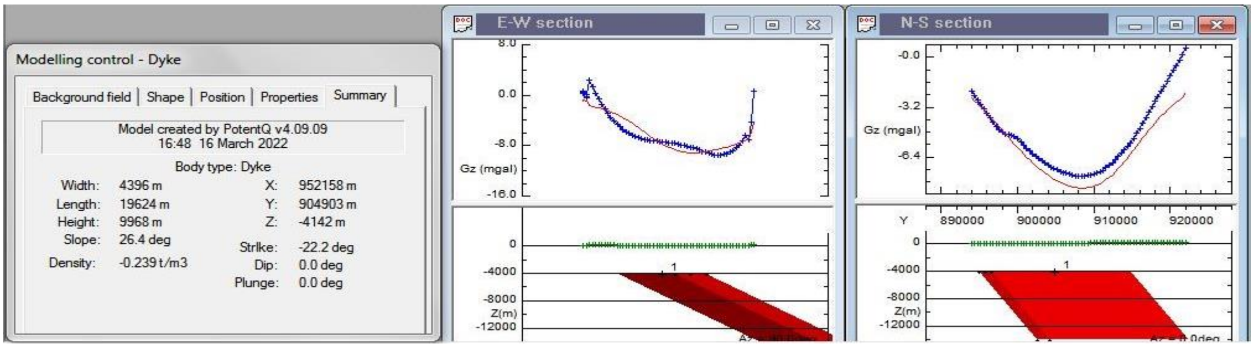

Figure 5: Point N3 modelled as a faulted anticline from a dyke model

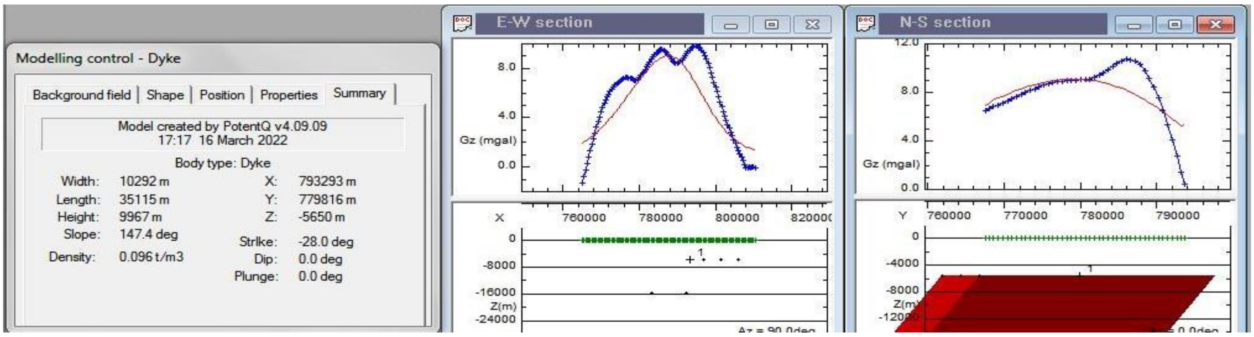

Figure 6: Point N4 modelled as a faulted anticline from a dyke model

The basement depths in the state from Euler depth estimation is shown in Figure 7.

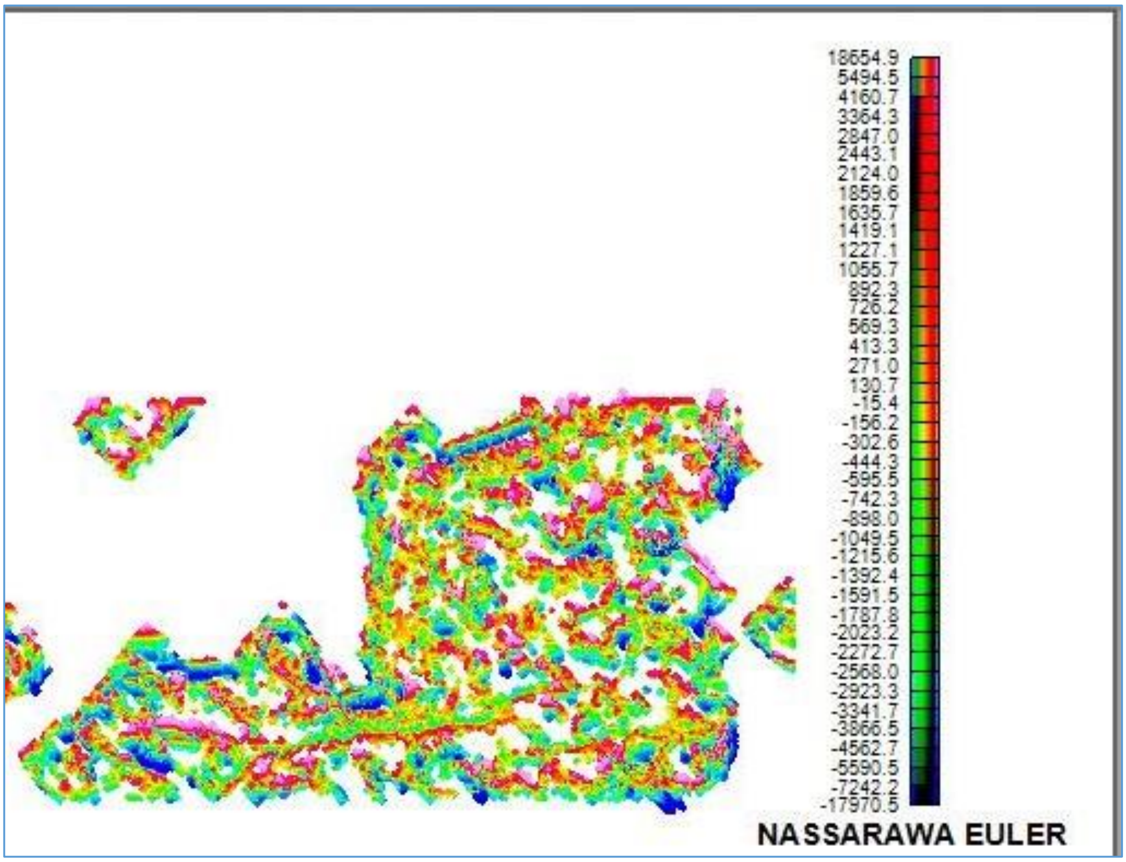

Figure 7: Basement depths from Euler deconvolution model

The Euler depth estimate values are reflected in the color legend bars with values from the deep to shallow sources reflecting sediment depths and depth to basements.

Discussion

The Bouguer gravity map in Figure 2 give the results of the subsurface mass/density distribution and structural trending in the state. The results indicate that formations in the central and northern parts of the state have high positive values which represents high mass density structures below the surface. The regions in the western, northwestern and southeastern parts of the state have lower negative Bouguer gravity values that indicate low mass density structures beneath the surface. The contour enclosures give the structural trending of the subsurface formations which can be identified as trending in east-west, northeast-southwest, north-south and northwest-southeast directions.

Normally, the wavelength of a Bouguer gravity anomaly is an indication of the depth of the anomalous mass, with large and deep density contrast bodies giving rise to broad long-wavelength anomalies as in regional anomalies. Residual anomalies which are shallow masses, give short narrow and sharp wavelength anomalies. In sedimentary basins, short- or intermediate-wavelength anomalies may arise from structures related to reservoirs for petroleum or natural gas. The common wavelength high pass filters used in this work removed the long wavelength anomalies (regional trends) from the observed gravity thus enhancing local anomalies with short and intermediate wavelengths as depicted in the models. From the base map and the contour clusters of Figure 2, the points marked N1 to N4 were selected for modelling utilizing dyke models. The results as reflected in Figures 3 to 6 show syncline and anticline structures at depths of 4141 m to 7991 m, density contrast from 0.239 m^{-3} to 0.90 gm^{-3} and zero dipping information for the various subsurface structures. We infer, from the dipping values, that we are dealing with horizontal layers or planes and this is equally consistent with the geology of the area. The results also show strike angles of varying degrees indicating prevalent faulting system types of strike-slip. Hence we can infer that the faults are normal faults caused by extensional or tensional forces. These faults can be observed at varying degrees of strike angles for model N1 at 9.1, model N2 at 21.2 ^{o}, model N3 at 22.2^{o}, and model N4 at 28.0 ^{o}. Faulted anticlines were observed on model N1, model N2, and model N4 while a synclines was observed on model N3. We note that, simple folded symmetrical anticline produces a symmetrical positive gravity anomaly, while normal faulted anticlines of a sedimentary sequence have density values that increase with depth as is consistent with the models. Model wise, this structure produces a broad maximum gravity anomaly indicating the areal-extent of the entire uplifted section. From the models, it was deduced that the faults trends evenly E-W and N-S.

The Euler depths estimate results of the state (Figure 7), reveal sediment depths across the state ranging from 15 m to 7991 m. This correlates to the basement depths within the state. The implication for these results is that some regions in the state have potentials for hydrocarbon formation and reservoirs because the sediment depths are thick enough and are conducive for the formation of hydrocarbon and the faulted structures are ideal environment for hydrocarbon reservoirs. More so, this region is adjacent to Bida Basin which has been identified with hydrocarbon potentials (Samuel, 2019; Obaje et al., 2011).

Conclusion

Aerogravity data analysis of the subsurface of Nasarawa state, Nigeria, reveal that the formations in the central and northern parts of the state have high positive values indicating formations of high mass density below the surface while regions in the western, northwestern and southeastern parts of the state have lower negative Bouguer gravity values that indicate formations of low mass density beneath the surface. The subsurface structures trend east-west, northeast-southwest, north-south and northwest-southeast directions. The prevalent faulting system in the survey area is the strike-slip faults which are normal faults, caused by extensional or tensional forces. These faults can be observed at varying degrees of strike angles for model N1 at 9.1, model N2 at 21.2 ^{o}, model N3 at 22.2^{o}, and model N4 at 28.0 ^{o}. Faulted anticlines were observed on model N1, model N2, and model N4 while a synclines was observed on model N3. The syncline and anticline structures exist from depths of 4142 m to 7991 m in sampled areas with sediment/basement depths ranging from 15 m to 7991 m across the state. The probability of hydrocarbon existing in some parts of the state is high.

Acknowledgement

The authors highly acknowledges Bureau Gravimétrique International (BGI), for the use of aerogravity data extracted for this work.

References

Adeleye, D.R. (1974). Sedimentology of the fluvial Bida Sandstones (Cretaceous) Nigeria. *Sedimentary Geology*, *12*, 1-24.

Adewumi, T. & Salako, K.A. (2017). Delineation of mineral potential zone using high resolution aeromagnetic data over part of Nasarawa State, North Central, Nigeria. *Egyptian Journal of Petroleum*, *27*(4), 1-8.

Alexander, B.C., Aloni, C. & Amen, E. F.D (2015). Geographical Survey of Nigerian Mineral Resources: A Step toward Planned Development. *Journal of Culture, Society and Development*, *6*, 38-43.

Ali, H.O, & Whitely, R.J. (1981). Gravity exploration for groundwater in the Biara Basin, Sudan. *Geoexploration*, *19*(2), 127-141.

Ali, A., Hossein, N. & Omid, O. (2013). Application of least squares and Euler deconvolution for solving inverse problems and locating the source of potential field. *Global Journal of Science, Engineering and Technology, (14),* 149-156.

Allis, R. G. & Hunt, T.M. (2016). Analysis of exploitation-induced gravity changes at Wairakei geothermal field. *Geophysics, (51),* 1647-1660.

Alsadi, H. & Baban, E. (2014). *Introduction to Gravity Exploration Method* (1st ed.). University of Sulaimaniyah: Cambridge Press.

Amoah, B.K., Dadzie, I. & Takyi-Kyerremeh, K. (2018). Integrating gravity and magnetic field data to delineate structurally controlled gold mineralization in Sefwi Belt of Ghana. *Journal of Geophysics and Engineering*, *15*(4), 1197-1203.

BGI. (2022). *World Gravity data.* http://bgi.cnes.fr

Dobrine, M.B. (2010). *Introduction to geophysical prospecting* (4th ed.). McGraw-Hill.

Eke, P.O. Okeke, F.N. & Ezema, P.O. (2016). Improving the geological understanding of the Niger Delta Basin of Nigeria using airborne gravity data. *International Journal of Geography and Geology*, *5*(5), 97-103.

Google maps of Nasarawa State, Nigeria (2022). https://www.google.com/search?q=the+map+of+nasarawa+state&ei=

Hakim, G. & Chokri, J. (2017). Regional-residual separation of potential field: an example of Tunisia. *Journal of Applied Geophysics*, *137*, 8-24.

Handayani, L., Wardhana, D. D., Hartanto, P., Delinom, R., Bakti, H., & Lubis, R. F. (2018, February). Gravity survey of groundwater characterization at Labuan Basin. In *IOP Conference Series: Earth and Environmental Science* (Vol. 118, No. 1, p. 012015). IOP Publishing, Bandung, Indonesia.

Idzi, A.A., Olaleke, A.M., Shekwonyadu, I. & Christian, E.A. (2013). Geochemical studies of mineral bearing ores from Nasarawa Eggon and Udege Beki areas of Nasarawa State. *Nigeria International Journal Basic Applied Chemical Science, 3*, 93–108.

Kearey, P., Brooks, M. & Hill, I. (2013). *An introduction to geophysical exploration*. John Wiley.

Lowrie, W. (2017). *Fundamentals of Geophysics*. Cambridge University Press.

Mariita, N.O. (2010). Application of precision gravity measurement of reservoir monitoring of Oklaria geothermal field. *Proceedings: World Geothermal Congress 2010*, 2719-2724.

Obaje, N.G. (2009). *Geology and Mineral Resources of Nigeria*, *Lecture Notes in Earth Sciences.* Springer Verlag Berlin Heidelberg, 148-150.

Obaje, N.G., Musa, M.K., Odoma, A.N. & Hamza, H. (2011). The Bida Basin in north-central Nigeria: sedimentology and petroleum geology. *Journal of Petroleum and Gas Exploration Research*, *1*(1), 001-013.

Reynolds, J. M. (2015). *An introduction to applied and environmental geophysics*. John Wiley and Sons Publications.

Robinson, E. S., & Coruh, C. (2018). *Basic Exploration Geophysics.* John Wiley and Sons, Publications.

Samuel, S.A. (2019). The geology, petrography, and economic potential of parts of Nassarawa-Eggon and Environs, North Central Nigeria. *Environmental and Earth Science Research Journal*, *6*(1), 24-34.