ISSN 2309-3218

AIRBORNE GRAVITY DATA INTERPRETATION FOR SUBSURFACE STRUCTURES AND IMPLICATIONS FOR HYDROCARBON PROSPECTS IN KOGI STAT E, NIGERIA

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ABSTRACT

Airborne gravity data of Kogi State, Nigeria, obtained from Gravimétrique International (BGI) has been interpreted for subsurface structures and implications for hydrocarbon prospects in the state. The extracted residual Bouguer gravity from the field data was enhanced with a first order filtering operation, gridded to produce a Bouguer gravity map and some selected points were modelled to obtain the desired results. These were achieved by processes of contouring, forward and inverse modelling and Euler depth estimation using the Oasis Montaj software. The results show subsurface formations with Bouguer gravity values of -13.4 mgal to 44.2 mgal within the state. Some regions in the southwestern, southeastern, northwestern and northeastern parts of the state have low gravity values which corresponds to subsurface formations with low density mass distributions. High density subsurface formations were identified in the southwestern, northern, and central parts of the state. The subsurface structural types interpreted are mostly faulted synclines and anticlines with structures trending in southwest-northwest in the northern parts of the state and east-west; north-south in the central parts of the state while in the southeastern part, structures trend in south-east directions. The sediment depths which also corresponds to depth to the basement in the state ranges from 53.7 m to 8890 m. These sediment depths have implications for hydrocarbon formation and accumulation as the sediment thickness are favorable environments for hydrocarbon formation while the structural types are suitable potential hydrocarbon reservoirs. It is recommend that more geophysical surveys be carried out to exploit the hydrocarbon potential of the state.

Keywords: Subsurface structures, formations, sedimentary thickness, hydrocarbon, modelling

INTRODUCTION

Obaje (2009) shows that Nigeria is endowed with a lot of natural mineral resources which have not been fully exploited. Except from hydrocarbon which is predominantly explored in the Niger delta, other parts of the country also have natural minerals including the hydrocarbon that have not been fully exploited. Kogi State is one such region in the country, with so many identified natural mineral resources including hydrocarbon (Fatoye, 2018). One reason for the under exploitation of these minerals is, Nigeria's over dependence on the hydrocarbon resources from the Niger delta coupled with sparse information on subsurface geology of some regions of the country. As pointed by Eke et al. (2016), Nigeria is among the richest in petroleum resources in the world with revenue from this sector accounting for over 90% of its gross domestic product. With the national revenue and most companies operations tied to the crude oil industry, there is the push to discover new oil wells as well as diversify the mineral exploration industry in the country. Airborne gravity data are good for several geophysical studies including regional and residual anomaly studies (Ali and Whitely, 1981; Allis and Hunt, 2016; Dobrine, 2010; Telford et al., 2016). Usually gravimeters mounted on aircrafts and flown at some altitude along line spacing's record gravity gradients of subsurface formations along the profiles. The survey is typically depending on the target of investigation. The physical property of interest is the gravity gradient which is the rate of change of the gravitational field in a determined direction Reynolds, 2015). According to Robinson and Coruh, (1998) the method offer cost effective and time saving means of surveying large areas and delivering high resolution data that could help delineate mineral hosting geologic structures with high accuracy and precision.

Generally, the variation of the Earth's gravitational field are caused by many factors, but the conceptual framework of the gravity method is based on the lateral variation of subsurface rock-densities. These variations can be measured by a gravimeter at the Earth's surface with the resulting density contrast in a surveyed region reflecting the geological anomaly or anomalies associated in that region. A given rock body whose density is different from its surrounding medium, which is a geological anomaly, produces a corresponding disturbance, called the gravity anomaly, in the Earth's gravity filed. The nature of these anomalies are influenced by their form, amplitude and nature of the subsurface geological anomaly. The anomaly of interest in most gravity interpretations is the Bouguer gravity anomaly which fromAlsadi and Baban (2014) is

$$\Delta g_B = g_o + (g_{FA} - g_{BC} + g_T + g_{lat}) - g_n \qquad 1.$$

It is a mixture of the regional and residual sources obtained from the corrected field gravity value (Lowrie, 2017).

LITERATURE REVIEW

Kogi State, referred to as the confluence state of Nigeria, is located in central Nigeria. It lies within latitudes 7° 48' 8.352" and 7° 48.1392"N and longitudes 6° 44' 0.348" and 6° 44.0006' E with the surrounding states of; Niger State in the north, the Federal Capital Territory (FCT) Abuja and Nasarawa State in the northeast, Benue State in the east, Enugu State in the southeast, Anambra and Edo States in the south, Ondo and Ekiti States in the west and Kwara State in the northwest (Fig.1).

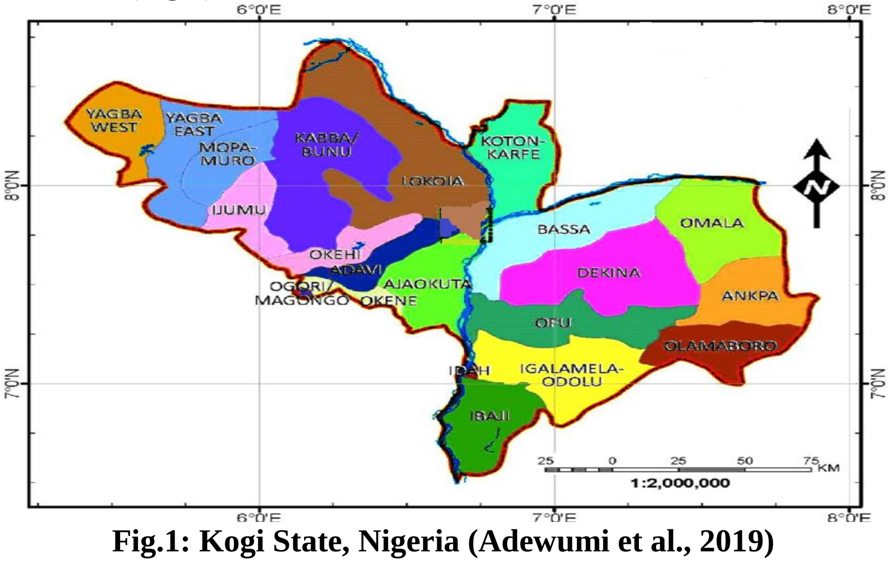

Fig.1: Kogi State, Nigeria (Adewumi et al., 2019)

The state lies in the Bida basin of Nigeria (Obaje et al., 2011). Approximately half of its subsurface formation is covered by crystalline Basement Complex of Precambrian Age while the other half is covered by Cretaceous to Recent sediments (Fatoye, 2018). The Basement Complex are part of the western geological Basement basin of Nigerian while the sedimentary area, is part of the Anambra Basin. The prevailing principal litho-facies are coarse pebbly sandstone and sand bodies, shale, limestone, clay and mudstone (Abbas and Adetola, 2013). Most subsurface interpretations of the region are based on solid mineral exploration, structural and depth analysis using radiometric and magnetic data (Kwaghhua et al., 2012; Tsepav and Mallam, 2017; Amoah et al., 2018; Adamu et al., 2012).

METHODOLOGY

The data for this interpretation was extracted from a pool of airborne gravity survey data by the Bureau Gravimétrique International (BGI) an International Association of Geodesy (IAG). The extracted data was processed with the aid of Oasis Montaj software. The extracted Bouguer gravity was enhanced using a first order filtering operation. This was gridded and the regional anomaly separated from the residual anomaly using a second order polynomial operation of

$$g_r = a_o + a_1 x + a_2 x^2 + \ldots\ldots\ldots. + a_n x^n \qquad 2.$$

A Bouguer gravity base map was produced from the residual anomaly. This was contoured and some selected points were modelled for structural and depth information. Basement and sedimentary depth estimates using the Euler deconvolution menu analysis of the software were obtained based on the relationship (Ali *et al.*, 2013)

$$(x - x_o)\frac{\partial T}{\partial x} + (y - y_o)\frac{\partial T}{\partial y} + (z - z_o)\frac{\partial T}{\partial z} = \eta(T - B) \qquad 3$$

Where $(x_0, y_0\ and\ z_0)$ is the position of the gravity source whose total field T is detected at x, y and z. The total field has a regional value B and η is the structural index.

RESULTS

The Bouguer gravity base map of Kogi State obtained from the interpreted field data is shown in Figure 2. It shows the variation of subsurface formation density across the state.

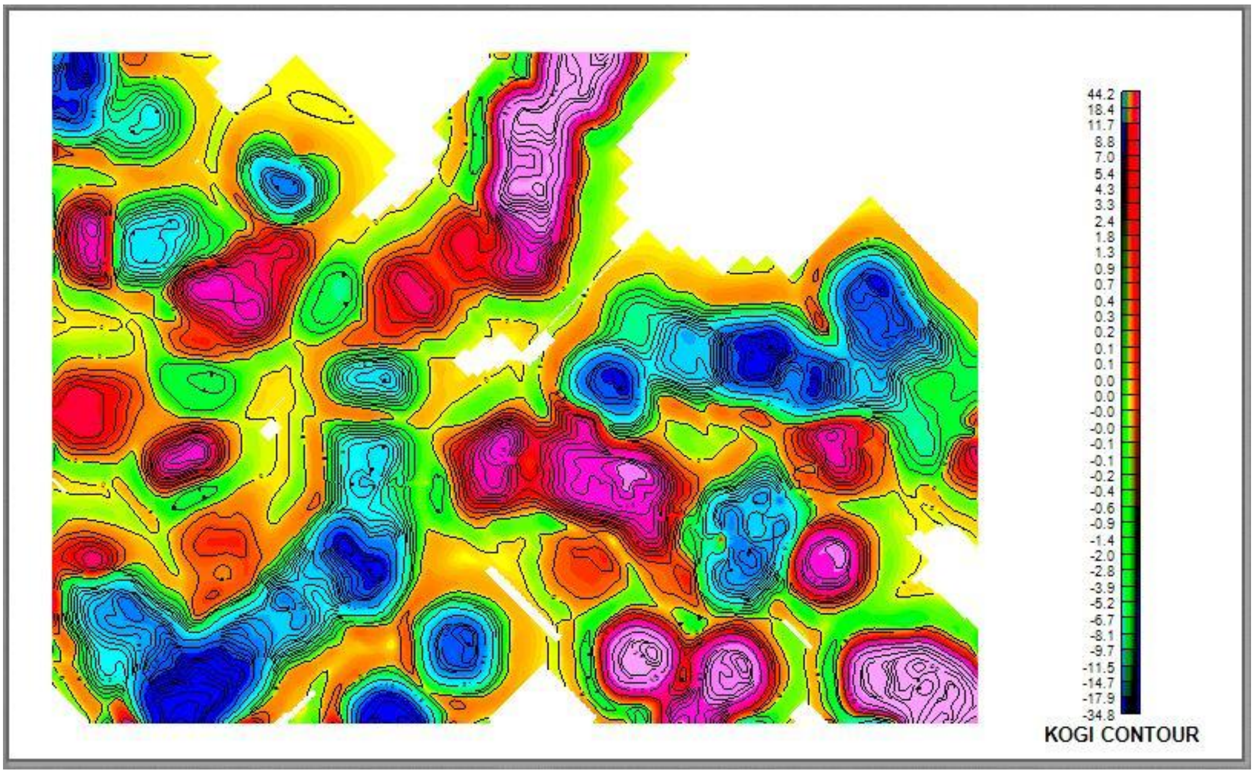

Fig 2: Bouguer Base Map of Kogi State with a legend bar

The values range from -34.8 mgal to 44.2 mgal and gives indication of the subsurface mass distribution of the formations.

Figure 3 shows the structural trending in Kogi State from a contouring intervals of 5 mgal.

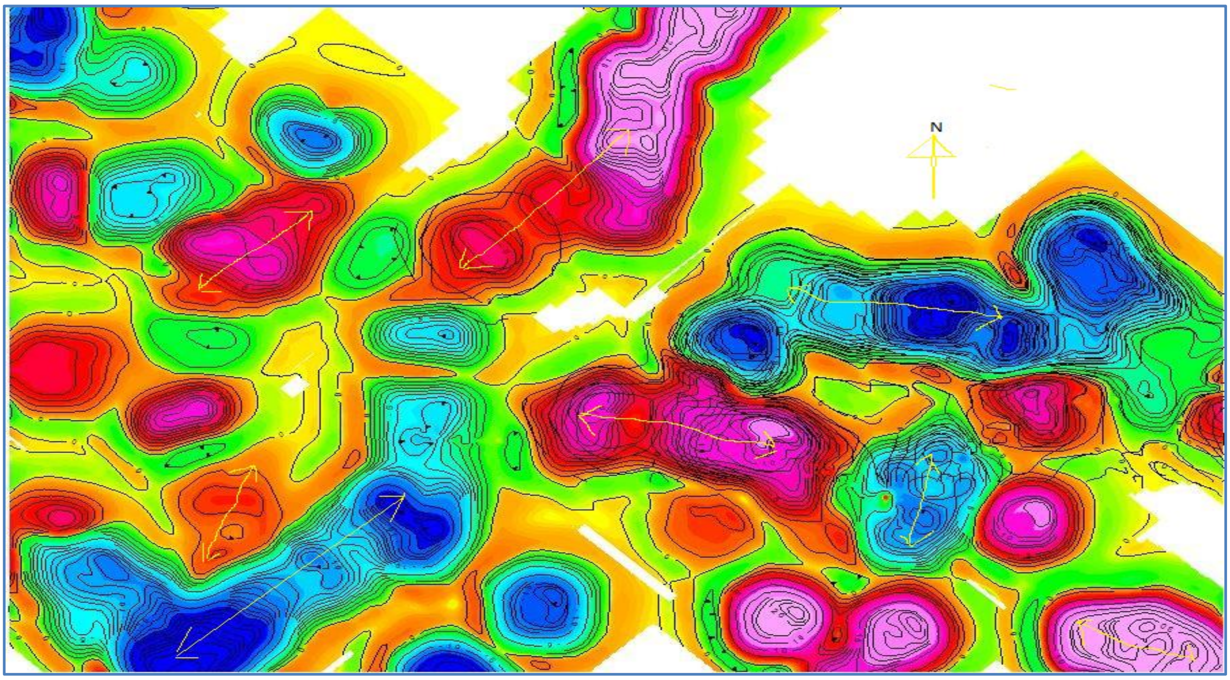

Fig. 3: Structural Trending in Kogi State

The contour enclosures follow patterns of the subsurface structural trending in the state as indicated by the arrows.

Figure 4 is the Bouguer base map of the state indicating the K1, K2, K3, K4 and K5 that were modelled for depth and structural type information, while Figures 5 to 13 show the forward and inverse modeling results. Table 1 is a summary of the modelled results.

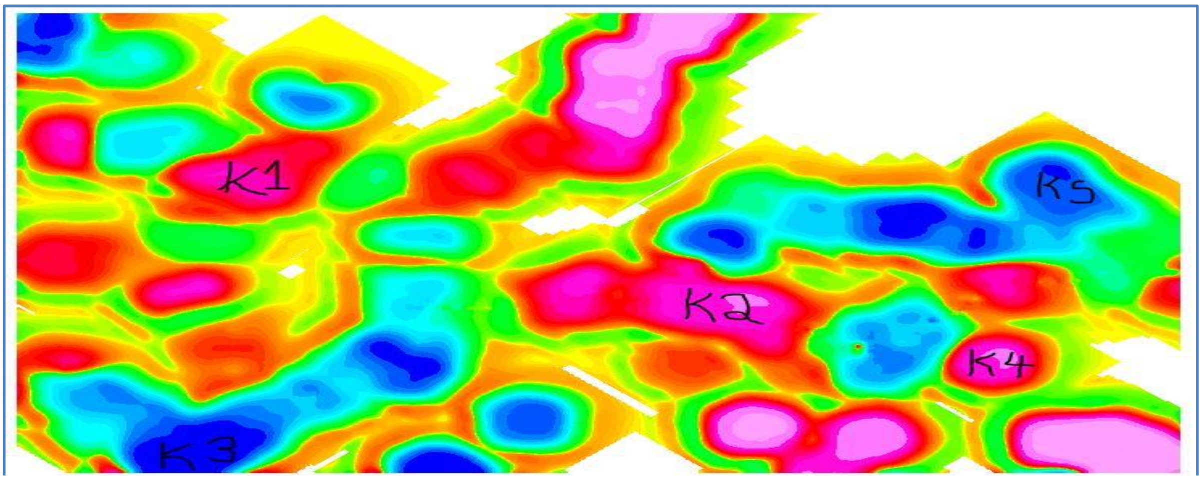

Fig.4: Map indicating modelled points for depth and structural type information

Figures 5 to 14 are the best fit inverse and forward modelling results of the selected points K1 to K5 using sphere and dyke models of the Oasis Montaj software

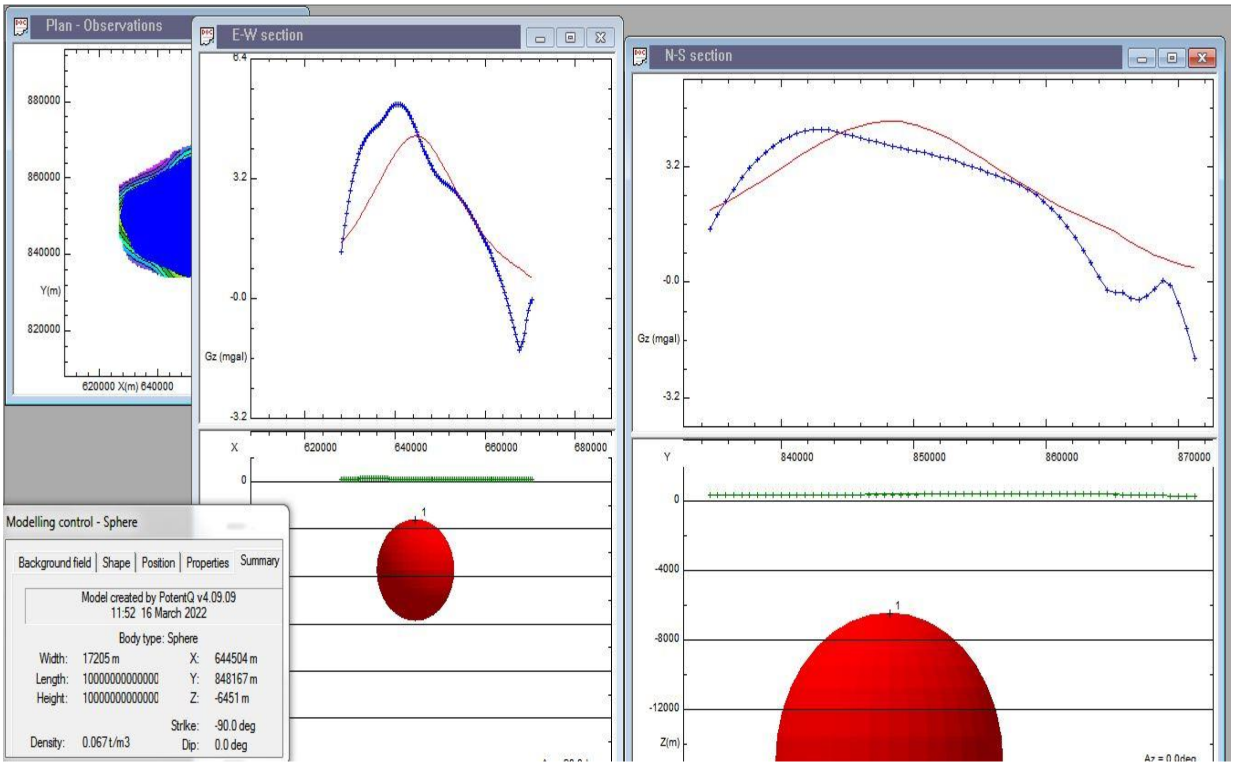

Fig 5: Result of model point K1using a sphere model

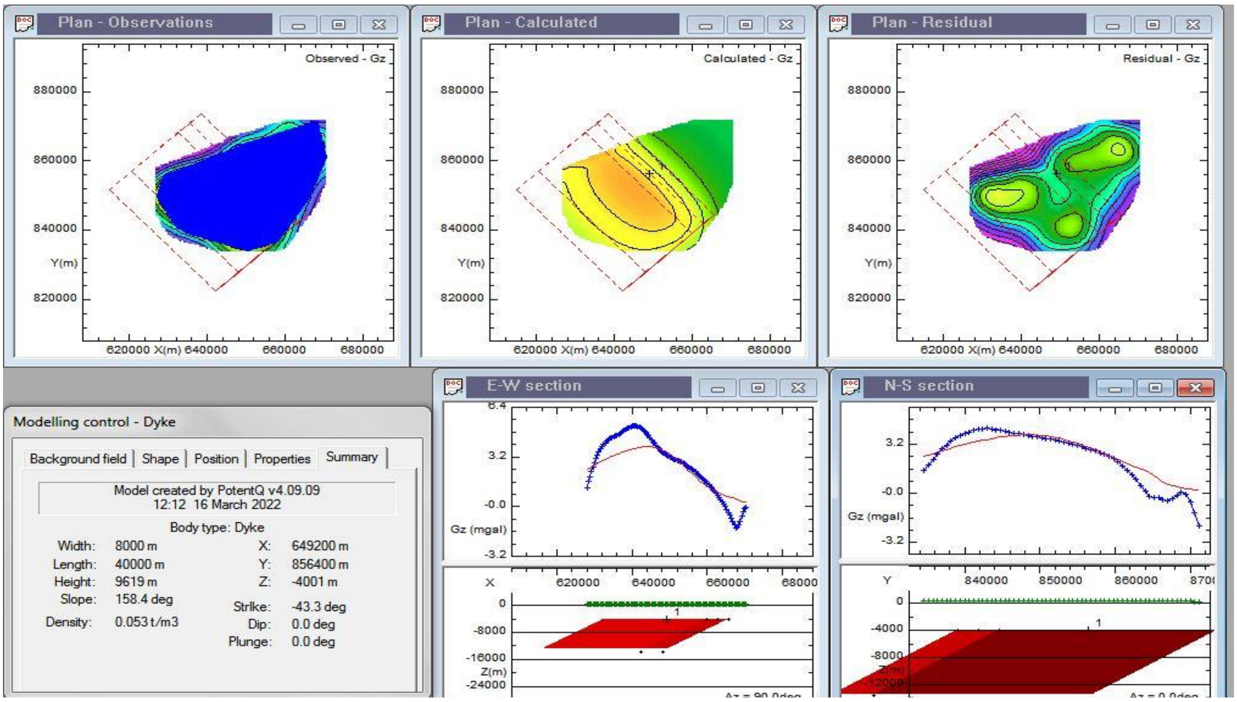

Fig 6: Result of model point K1 using a dyke model

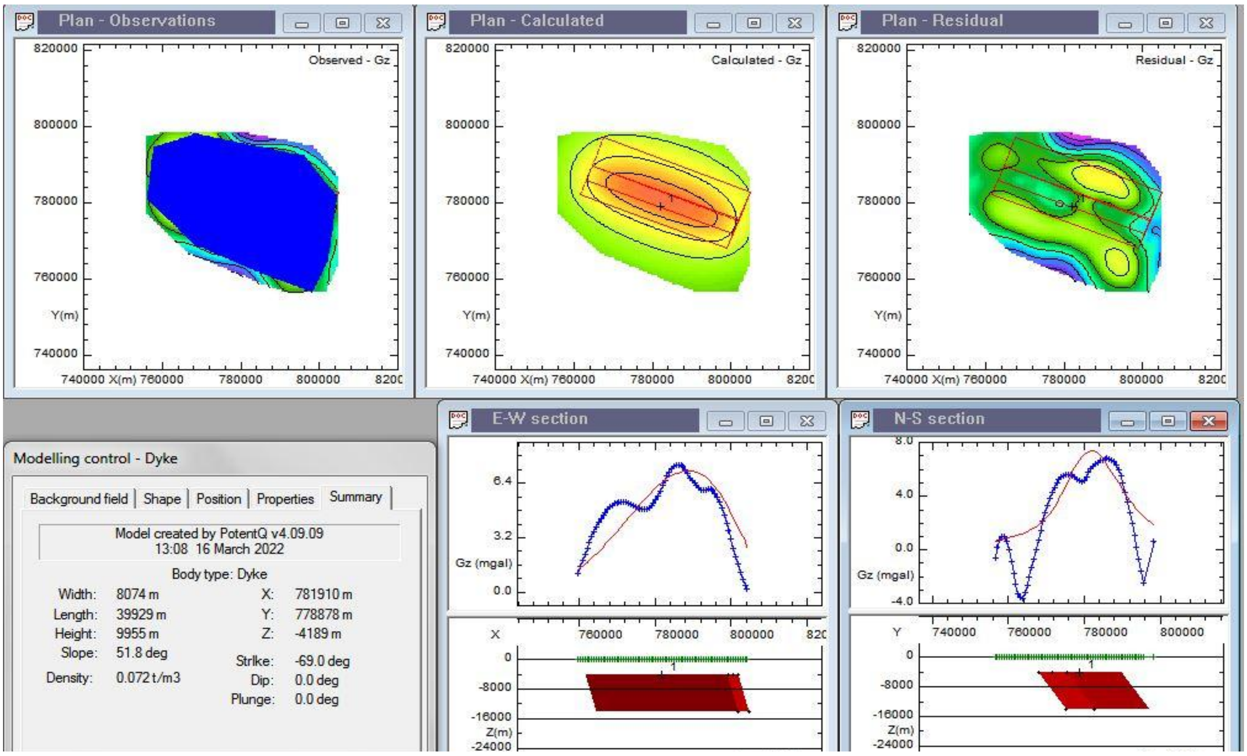

Fig 7: Result of model point K2 using a dyke model

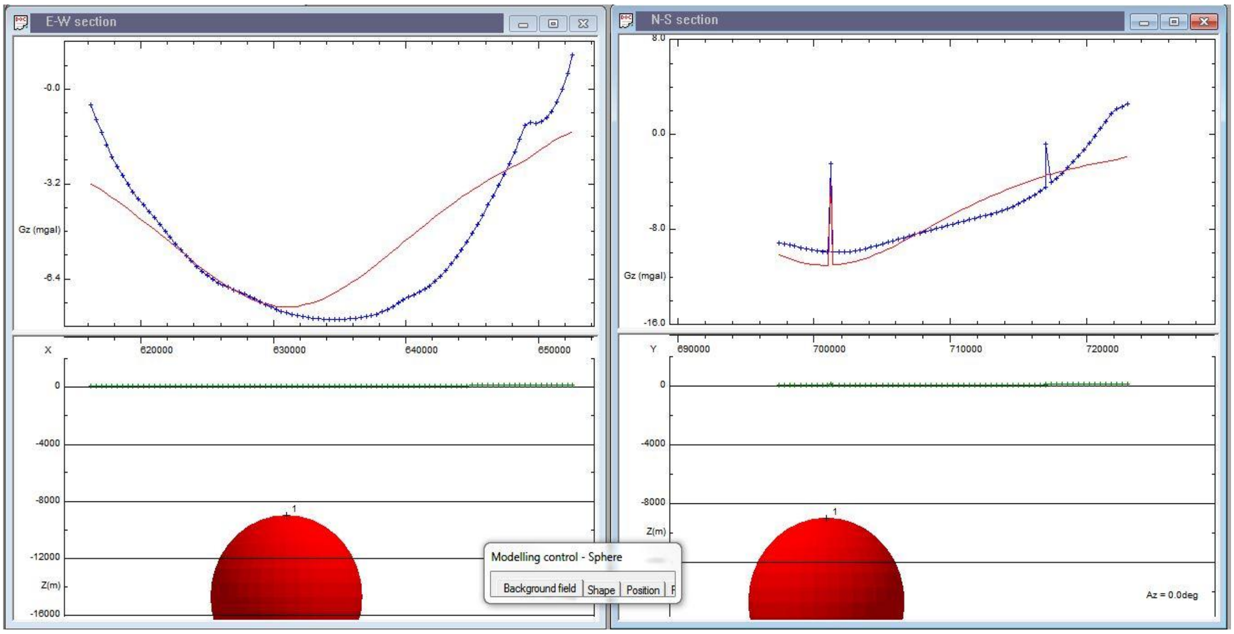

Fig 8: Result of model point K2 using a sphere model

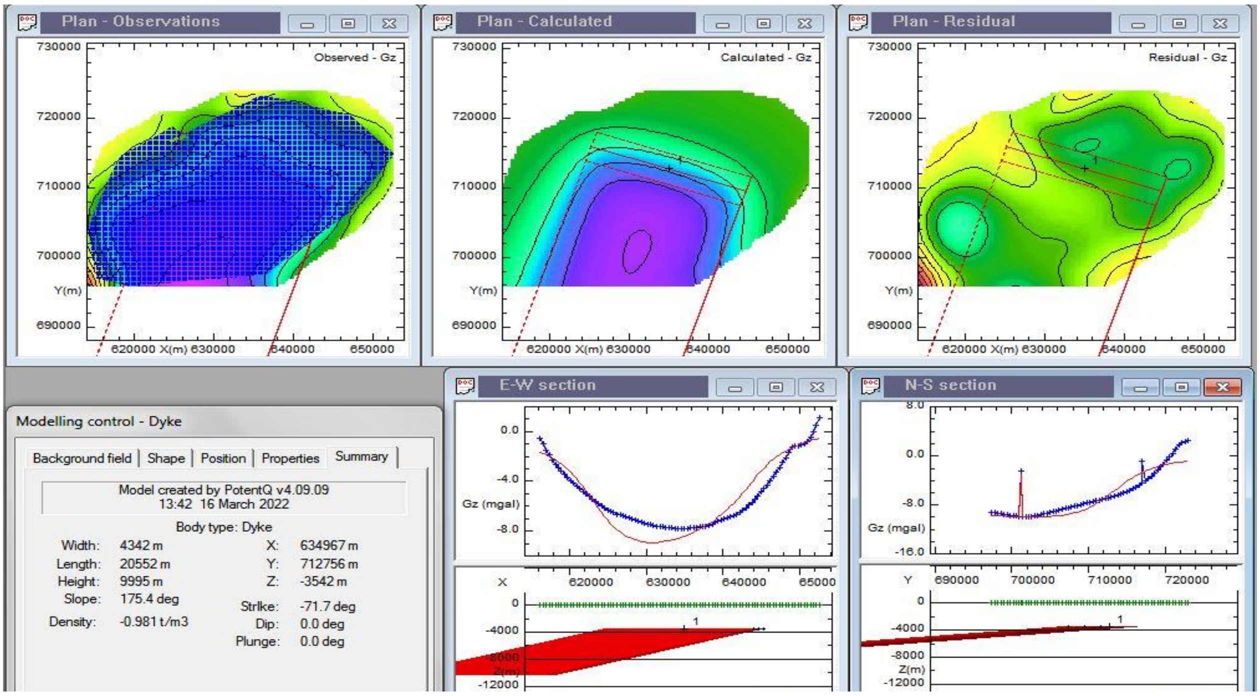

Fig 9: Result of model point K3 using a dyke model

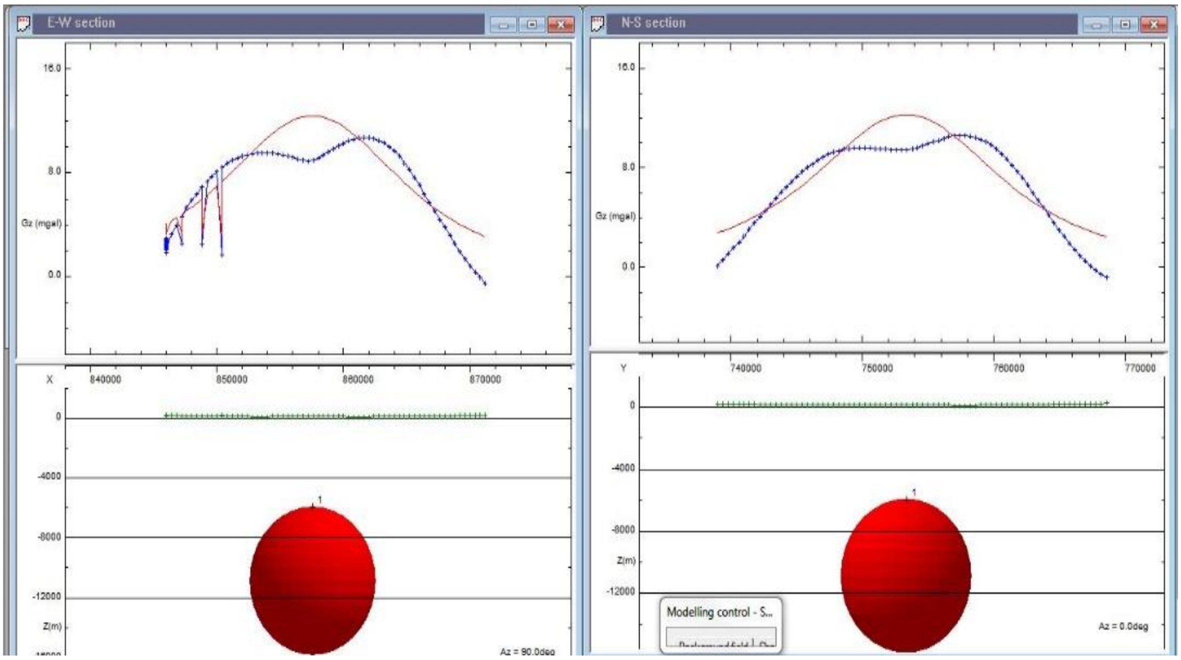

Fig 10: Result of model point K4 using a sphere model

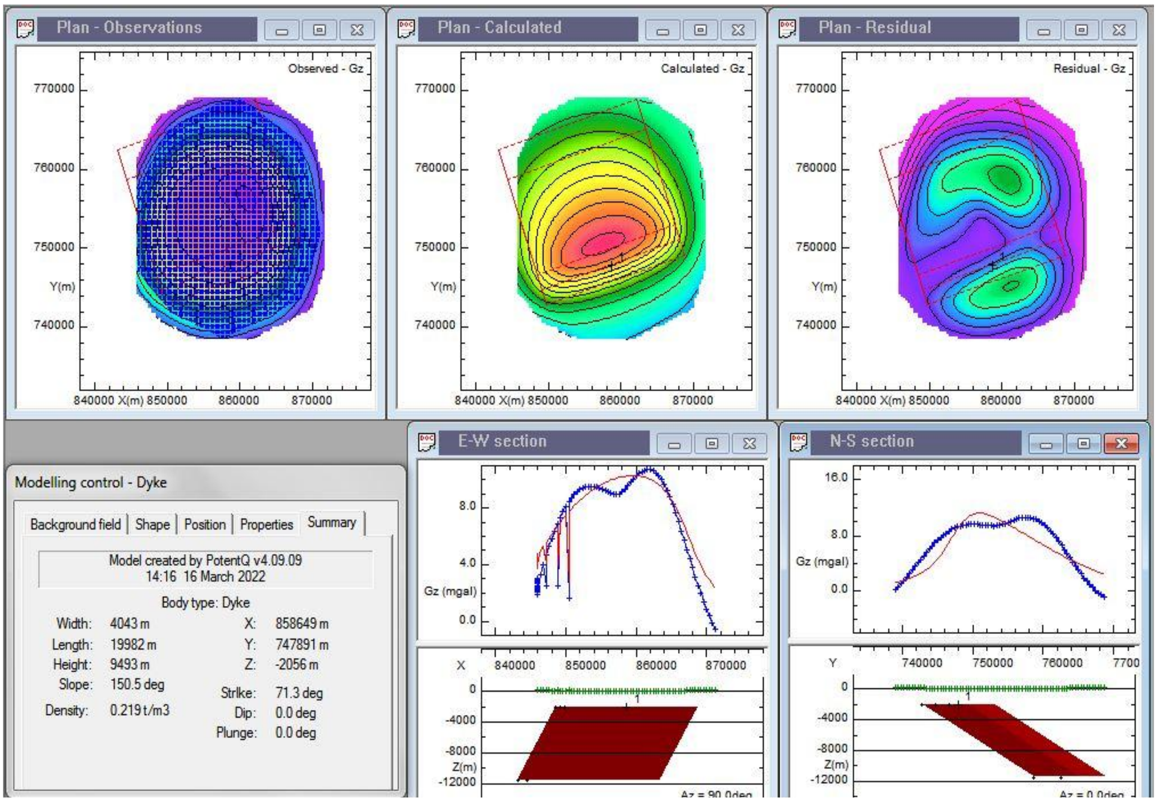

Fig 11: Result of model point K4 using a dyke model

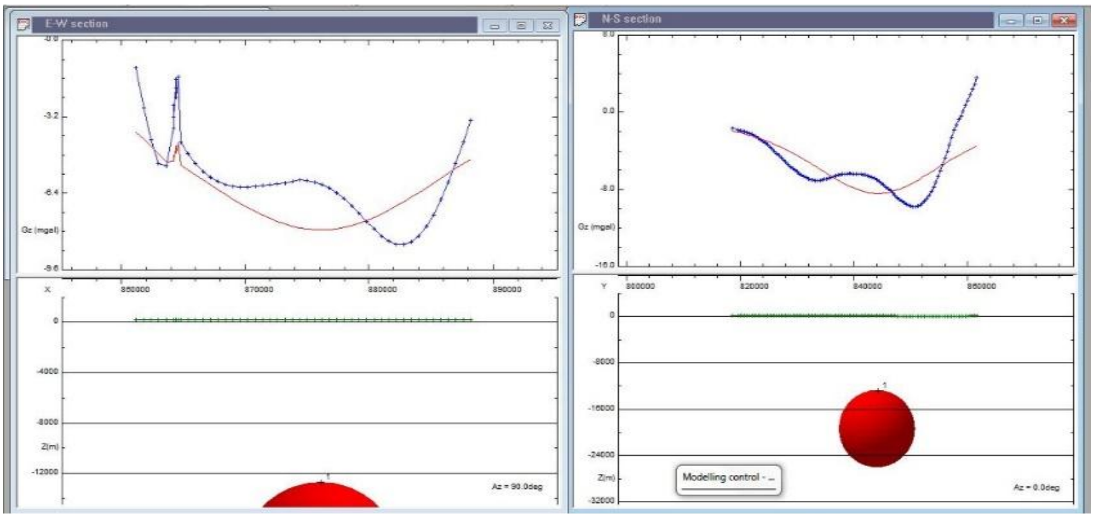

Fig 12: Result of model point K5 using a sphere model

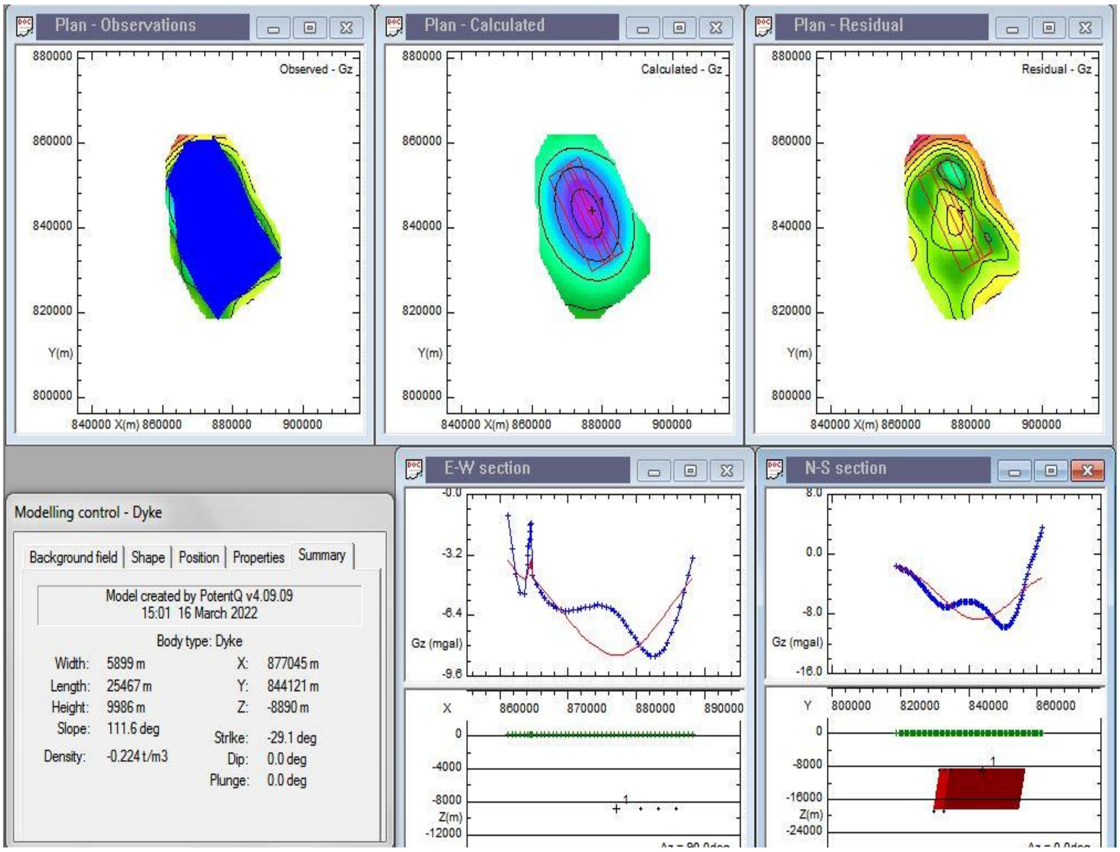

Fig 13: Result of model point K5 using a dyke model

Basement depths from Euler estimates for the state is shown in Figure 14.

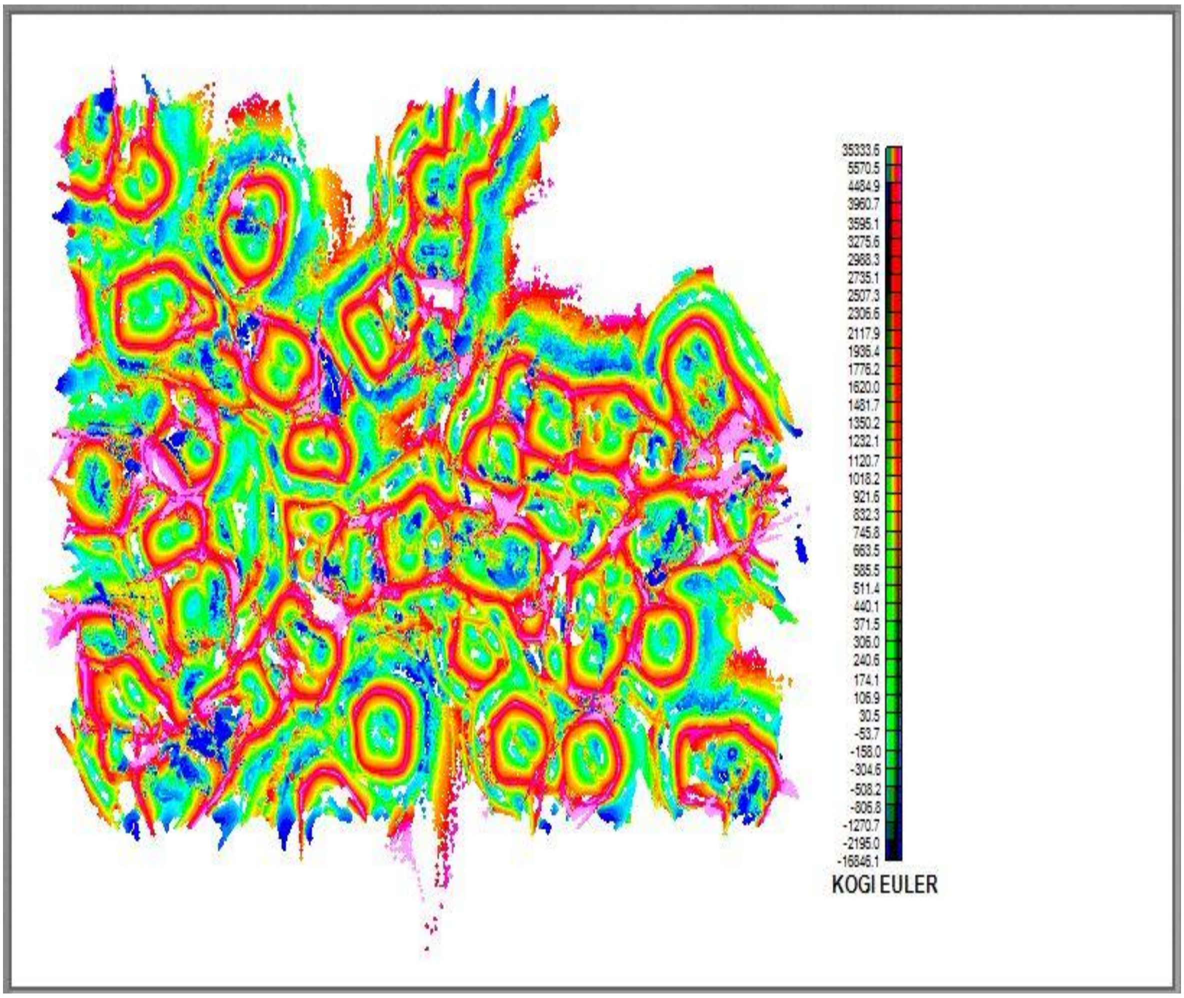

Fig. 14: Basement depth result from Euler estimates

Table 1 summarizes the structural types, depth to anomaly, density contrast and possible potential hydrocarbon reservoirs in the study area.

Table 1: Models summary results indicating depths to anomalous bodies.

Model	Depth to anomalous bodies (m)	Density contrast of thebody (g/cm^3)	Model Shape (Dyke)	Possible cause of the anomaly.
K1	4001	0.053	Faulted syncline	Hydrocarbons / Natural Gas
K2	4189	0.072	Faulted syncline	Hydrocarbons / Natural Gas
K3	3542	0.981	Faulted syncline	Hydrocarbons / Petroleum
K4	2056	0.219	Faulted anticline	Hydrocarbons / Natural Gas
K5	8890	0.224	Faulted syncline	Hydrocarbons / Natural Gas

DISCUSSION

The contour Bouguer base map in Figure 2 show thesubsurface Bouguer gravity spread of the formations in the state.With a contour interval of 5mGal, the results reveal that subsurface formations in the state have a minimum of -34.8 mGal and a maximum of 44.2 mGal. Subsurface formations with low gravity values, that is structures with low density mass, can be found in the southwestern, southeastern, northwestern and northeastern regions of the state. High Bouguer gravity values which translates to high density mass subsurface structures can be found in the northern, central and southwestern parts of the state. The contour enclosures from Figure 3 follow the patterns of the subsurface structural trending in the state as depicted by the arrows. In the northern part of the state, we can identify structures trending in southwest- northeast directions. The same applies in the southwestern part of the state. In the central part of the state, we can identify east-west and north-south trending structures. Similarly, we can also identify south-east subsurface trending structures in the south eastern part of the state.

Most of the structures in the areas are majorly faulted anticlines which are usually found in practically all hydrocarbon reservoirs and are crucial elements because they both influence the migration of hydrocarbon within the reservoir and contribute to the entrapment of fluids. Careful comparison of the models with the interpretational techniques of gravity signatures of various geological models (Prieto, 1996) agrees with these. The standard recognized fault signature is a steep gradient. In the gravity case the gradient deepens as the faults becomes shallower. For a normal fault, two cases are possible, normal faults with one high density layer and normal faults with one low density layer. A syncline produces a minimum closure on most geophysical maps. The amplitude and characteristics of the gravity anomaly associated with a syncline depends on depth, type of sedimentary fill, the amount of sedimentary warping and the involvement of basement rocks. A syncline can often be masked on the seismic sections by diffractions or velocity problems but it is rare that gravity data cannot verify a synclinal structure (Prieto, 1996).

The survey reveals that, faulted anticlines were observed on Model K1, Model K2, and Model K4 while faulted synclines were observed on Model K3 and Model K5. Simple folded symmetrical anticline produces a symmetrical positive gravity anomaly. While normal faulted anticline consists of a sedimentary sequence of density values that increase with depth and a faulted basement uplift. This structure produces a broad maximum gravity anomaly indicating the area extent of the entire uplifted section. From the models, it was deduced that the faults trends evenly E-W and N-S. All our models for the study area indicated a dipping of 0, this implies that we are dealing with horizontal layers or planes and this is consistent with the geology of the area. Our models shows strike angles of varying degrees, showing us that the prevalent faulting system in the survey area is the strike-slip. Strike-slip faults are also known as a wrench, tear or trans-current faults. Hence we can infer that the faults are normal faults caused by extensional or tensional forces. Faults were observed at varying degrees of strikes For Model K1 at 43.3 degrees, Model K2 at 90.0 degrees, Model K3 at 71.7 degrees, Model K4 at 71.3 degrees, and for Model K5, 29.1 degrees.

The density obtained could either have a positive sign or a negative sign with a positive density contrast indicating anomalous body with higher density than the host rock or surrounding layer while a negative density contrast indicates that the anomalous body has a lower density than the surrounding host rock or layer. Positive anomalies are often associated with anticlines while negative anomalies are associated with synclines. From the model results and Euler estimates, the sediment depths in the state range from 53.7 m to 8890 m. These also indicate the depth to basement in various parts of the state. The thickness of these sediments make some regions of the state potential hydrocarbon regions and we infer that from the modelling and structural types encountered, regions with modelled points K1 to K5 are potential hydrocarbon regions.

CONCLUSIONS

This study reveals that the Bouguer gravity spread of subsurface formations in Kogi State, Nigeria varies from -13.4 mgal to 44.2 mgal. The low Bouguer gravity density regions are in the southwestern, southeastern, northwestern and northeastern parts of the state and these correspond to subsurface formations with low density mass structures. The high Bouguer gravity density regions corresponding to regions with subsurface formations of high density mass structures which are found in the northern, central and southwestern regions of the state. Dominant subsurface structural types are faulted synclines and anticlines. Structures within the subsurface trend in southwest-northwest in the northern parts of the state; east-west, north-south in the central parts of the state and south-east in the southeastern part of the state. Sediment depths which also corresponds to depth to the basement in the state ranges from 53.7 m to 8890 m. These sediment depths and structural types make some regions in the state potential hydrocarbon regions.

ACKNOWLEDGEMENTS

The authors acknowledges Gravimétrique International (BGI)an International Association of Geodesy (IAG) for the gravity data used in this work.

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