

Improved Subsurface Exploration of Gongola Basin, Nigeria Determined from Source Parameter Imaging of Gravity and Aeromagnetic Anomalies Via Statistical Error Analysis.

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Abstract- This research focuses on the potential of Gongola arm of the Upper Benue Trough in northeastern Nigeria, which falls between longitude 10° 00' E to 12° 00' E and latitude 9° 30' N to 11° 30' N. The potential of the Gongola basin comprises natural resources, with geothermal energy and hydrocarbon (oil and gas) being the main areas of concentration. The research discerns and characterizes zones of thick sedimentary overburden from those of uplifted or shallow basements to infer potential for oil/gas and mineral deposit accumulations. This was achieved by unveiling depths to magnetic sources reinforced with gravity sources as determined by Source Parameter Imaging (SPI) techniques. The result of the two adopted methods for SPI were in very close agreement with each other having a depth to deep sources of 9826 m and 8913 m), intermediate sources (5779 m and 4599 m) and shallow sources (below 1798 m and 1772 m). The normalized error ranges from 0.2 to 0.99 for the SPI. Depth above 4000 m were recommended for further oil and gas investigations while sources closer to the ground were recommended for mineral investigation. Therefore, this research provides precise information on the depth configuration of Gongola basin that might yield mineral oil or gas. It also serves as a guide to other researchers to build a confident interpretation of the subsurface through complementing methods.

Keywords: Gongola, Gravity, Aeromagnetic, SPI, Error.

I. INTRODUCTION

The current economic struggle facilitates more interest in the potential of the Nigerian inland basins such as the Gongola basin. The potential of the basin comprises natural resources, with geothermal energy and hydrocarbon (oil and gas) being the main areas of concentration. Intentions of extending national

exploration have seen exploratory effort has been ongoing within the basin. With greater attempts being made to find new reserves, the Gongola basin, a portion of the Upper Benue Trough, was examined to determine its configuration, specifically the depth to magnetic and gravity sources for potential accumulation of mineral resources and hydrocarbon (oil and gas). Magnetic and gravity exploration also known as potential field exploration is one technique used in harnessing the potential of the basin. Gravity and Magnetic surveys can be captured on land, at sea and in the air. A key component of contemporary geophysics is an airborne geophysical survey, which makes it possible to cover the exploration region more quickly and typically for less money as opposed to terrestrial or ground surveys.

Based on gravity and magnetic anomalies within the earth's subsurface, the characteristics of the underlying rocks can be studied to infer the subsurface geology (Ugwu et al., 2018). An induced magnetic anomaly's dimensions, shape, and amplitude depend on the body's orientation, geometry, size, depth, and magnetic susceptibility as well as the strength and inclination of the earth's magnetic field in the survey region (Ngozi et al., 2019; Ugwu et al., 2018). For exploration purposes, both ground and aerial potential data have been used to explore the existence of various mineral deposits in combination with gravity. Gravity and magnetic techniques are nonetheless often applied in the mining industry as exploration tools to survey the subsurface geology and assess ore reserves for some substantial ore bodies due to a difference in magnetic

and density content of rock forming mineral (Bassey et al., 2017; Ibe et al., 2022), hence the magnetic intensity and Bouguer gravity map allows imagining of the geological structures of the earth's upper crust, predominantly the spatial shapes of bodies of rock and the presence of conduits structures such as faults and folds. The primary goal of a potential field survey is to find rocks or minerals with distinctive density or magnetic characteristics that are revealed as anomalies (Anthony et al., 2023; Nwogwugwu et al., 2017; Odidi IG et al., 2020; Ugwu et al., 2018).

Numerous researches were conducted on the Gongola basin for the assessment of its depth to magnetic and gravity sources. The depth estimation techniques used involve Spectral analysis, SPI (Sources Parameter Imaging), Euler deconvolution and modelling. Spectral analysis has been positively applied in delineation of gravity and aeromagnetic data using Overlapping windows to establish a reliable and complete set of depth estimates (Adewumi et al., 2017; Ngozi et al., 2019; Nwobodo et al., 2018; Oghuma & Obiadi, 2015; Ogunmola et al., 2016; Spector & Grant, 1970; Ugwu et al., 2018).

The mentioned researches used only Spectral analysis to assess portion (110km by 55km) of the Gongola basin which limits the basins resources output. While (Bassey et al., 2017) used terrestrial gravity to cover less than 55km by 55km. Moreover, the Spectral technique is limited by number of windows there by producing isolated depths of ensembles that need to be interpolated over long distances to produce a sparse 2D map. For a basin wide survey there is a limit to the number of windows a researcher can calculate manually. On the other hand, SPI yield a complete 2D map with minimal user inputs as opposed to spectral analysis. SPI has been applied on High resolution aeromagnetic survey to evaluate the basement configuration of Gongola Basin (Salako, 2014). Spectral analysis and SPI have been simultaneously applied to either gravity or magnetic survey alone which limits the exploitation of the complementary nature of gravity and magnetic surveys in providing confident interpretation. To remedy this, spectral analysis and SPI were simultaneously applied to both gravity and magnetic survey to reinforce each other thereby yielding more precise results.

This current research aids as a scouting survey to comprehend the structural framework and the geometry of the Gongola basin which can pave the way for additional investigation to be conducted in the basin. It encompasses unveiling various depths to magnetic and gravity sources which were determined using SPI. The complementary results from these two procedures discern and characterize zones of thick sedimentary overburden from those of uplifted or shallow basements. The results were used to suggest the study area that has the potential for oil/gas and mineral deposit concentration.

1.2 Location and Geology of the Gongola Basin

The Benue Trough is itself a product of the West and Central African Rift System which it opened as a broad strike-slip fault system. The continents (South America, Africa, Arabia, Madagascar, India, Australia and Antarctica) are thought to have been one supercontinent called Gondwana land and the relative movement of the continental plates resulted in the formation of a triple junction where only two arms of the junction opened into the ocean and the third arm did not. The Benue trough is thought to be the failed arm of the triple junction which also led to the separation of the African and the South American plates (Ogunmola et al., 2016). The geology of the study area comprises Precambrian Basement rocks, Cretaceous to Recent sedimentary sequences and Tertiary volcanics (Olakunle & Abdulmumin, 2019). These basement rocks include the older Granite category which comprises granites, granodiorites and mylonites. The sedimentary formations from oldest to youngest are Bima, Yolde, Pindiga, Gombe and Kerri-Kerri. (Abubakar et al., 2010) among other authors.

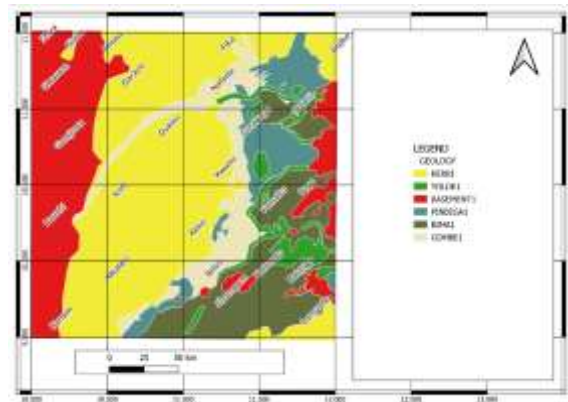


Figure 1 Geology of Gongola Basin

2.1 Source Parameter Imaging SPI

The SPI is a profile- or grid-based approach for quantifying the depth to gravity and magnetic sources, contrast in susceptibility, and dip of some source geometry. The method takes use of the link between the source depth (h) and the local wavenumber (k) of the observed field, which can be determined for every location within a data grid using vertical and horizontal gradients as follows. (Salako, 2014):

$$h = \frac{1}{k_{max}} \quad (1)$$

where k_{max} represents the peak value of k which is located over the step source, the expression for the k as a function of the field A in x and y direction is given by (Salako, 2014):

$$k = \sqrt{\left[\frac{\partial A}{\partial x}\right]^2 + \left[\frac{\partial A}{\partial y}\right]^2} \quad (2)$$

2.2 Normalized Absolute Error (NAE) and Normalized Mean Absolute Error (NMAE)

The Normalized Absolute Error (NAE) quantifies the discrepancy between expected and actual values, normalized by the data's range or mean. It assesses model correctness irrespective of unit scale. In the analysis of a dataset comprising many points, the error is generally consolidated into a Normalized Mean Absolute Error (NMAE). NMAE is a widely utilized measure due to the straightforward interpretation of its error value. This is due to the value being on the same scale as the target variable being predicted. The formula for computing Mean Absolute Error (MAE) is provided by Despotovic et al. (2016).

$$NMAE = \frac{\frac{1}{N} \sum_{i=1}^N |(u-v)|}{\frac{1}{N} \sum_{i=1}^N u} \quad (3)$$

where, u is the magnetic values, and v is the gravity values.

3.1 Materials and Methods

The materials used in this research include terrestrial gravity data, aeromagnetic data, Oasis Montaj software, Surfer 17 software, QGIS Software, and Microsoft Excel software. The Mentioned softwares

were used in the processing of the gravity and magnetic data. Oasis Montaj was used for the correction and processing of the potential field data gravity data. Surfer 17 and Microsoft Excel were also utilized in this research for plotting of graphs and images superimposition respectively. In addition, Surfer 17 they were also used to exchange data in different formats. Q GIS was however used in geologic and location map plotting.

3.2 Terrestrial Gravity Data Acquisition

The information for Terrestrial Gravity was provided by Gravimétrie Internationale (BGI) (<http://bgi.omp.obsmp.fr>). It consists of 235 data points that were dispersed throughout the entire study area. The data were provided by the British Antarctic Survey, Geological Survey of Nigeria, Department of Geology, University of Ibadan, Nigeria, and Geophysical Survey of The Southwestern Part of The Chad Basin.

3.3 Aeromagnetic Data Acquisition

The Geological Survey of Nigeria Agency provided the sixteen (16) high resolution aeromagnetic maps that make up the aeromagnetic data for the Gongola Basin (NGSA). The maps encompass of sheet numbers 107, 108, 109, 110, 129, 130,131,132, 150,151,152,153, 171,172, 173 and 174 which lies covers longitudes 10.000 E to 12.000 E and latitudes 9.300 N to 11.300 N. The survey was conducted along a series of NE-SW lines that were spaced roughly 500m apart, with an average flight over terrain with constant elevation of 80m above sea level.

3.4 Gravity and Magnetic Data processing

The data obtained was digitally combined with Oasis Montaj software to create a total gravity and magnetic intensity map of the research area. Later, using polynomial fitting, the anomaly map was subjected to regional and residual separation. The final anomalous map for magnetic survey was then subjected to reduction to the equator. The two maps where further subjected to source parameter imaging and spectral depth estimates.

3.5 Source Parameter Imaging (SPI) Method

The process starts with the SPI menu in Oasis Montag as follows. The first two grids Grid specify the horizontal derivative in the X and Y -direction. The Subsequent specify the vertical derivative in Z-direction. The Fourth Grid specify the tilt derivative and the Fifth Grid indicate the local wavenumber k grid (horizontal gradient of tilt derivative). After calculating and loading this grid, the SPI extensions return a database which was further grided into map.

3.6 Error Analysis

The results of the SPI grids (gravity and magnetic) obtained in the Oasis Montag was used as the inputs (u, v) for the grids maths in Oasis Montaj software to calculate the NMAE. Where, u is the magnetic values, and v is the gravity values. The Equation (3) was implemented in the grids maths utilities of the Oasis Montaj software with the inputs u and v. The result obtained for the normalized error was grided using minimum curvature and the result was displayed in (3c).

IV. RESULTS

The results obtained from spectral analysis and SPI techniques for both gravity and magnetic surveys as well as the analysis of their errors were carefully examined, and inferences drawn were discussed.

4.1 Residual Bouguer Anomaly

The residual Bouguer anomaly of the study area varies from -15 mGal to 12 mGal (Figure 2a). The colour legend bar identifies regions of gravity high (red and pink) which corresponds to regions with high density contrast beneath the surface; intermediate values (green and yellow) and gravity lows (blue colour) correspond to regions of low density contrast. Similar to the Bouguer anomaly, the residual Bouguer anomaly map shows the same pattern with more isolated pockets of anomalies as a result of shorter wavelengths. The Low mGal readings at the Central parts of the study area have been shifted down to the bottom part of the map which coincides with the known well log data, invariably indicating the deeper part of the Graben. The lowest Bouguer anomaly of -56 mGals) still maintain its trend in the NE direction. Closed negative anomalies are related to sedimentary basins

or grabens. The interested area has two main low negative anomalies the green low gravity anomaly of less than 1 mGal with reference to the colour legend bar and the lowest anomaly of -15 mGal indicated as the circular blue anomalies. The high values of gravity anomalies may be associated with the basement, uplifts and/or horsts located at the edges of the Study area. It includes the maximum gravity anomaly (-12 mGals), with main N to NE trends. The Discontinuity between the Basin and Basement anomalies may be associated with fault of the basement rocks and/or the sedimentary cover. The Basin Graben is Surrounded by the Horst from both edges.

4.2 Total Magnetic Intensity Reduced to Equator (TMI-RTE) Map

The RTE shows a varying intensity of 110.2 nT to -141.5 nT. The study area can be subdivided into four magnetic zones, each having a unique magnetic anomaly pattern (Figure 2b), this magnetic zoning is mainly dependent upon the magnetic properties of the underlying rock types. The fourth zone occupies the south-western, north-eastern and central parts of the research area. It is underlain by the Precambrian crystalline basement rocks with high susceptibility.

It is characterised by magnetic high intensity designated as B. The third zone occupies the South-Eastern parts of the area labelled C. It exhibits intermediate (positive) anomalies with amplitudes of the magnetic intensity designated as intermediate on the colour legend bar. The Second zone Labelled D houses both high and low magnetic intensities. The First zone designated as A is the most dominant feature on the map. It displays relatively negative to positive magnetic anomalies. Amplitudes of the magnetic intensity in this zone were labelled low on the colour legend bar. Few isolated anomalies occurred within the study area. These are the sources with the least susceptibility of all the four classes. Their anomalies trend mainly in the South-West to North-East direction. It is underlain by sediments. The RTE map differ from the TMI and residual by aligning the anomalies more to the SW-NE trend as the anomalies transformed directly over their respective causative bodies.

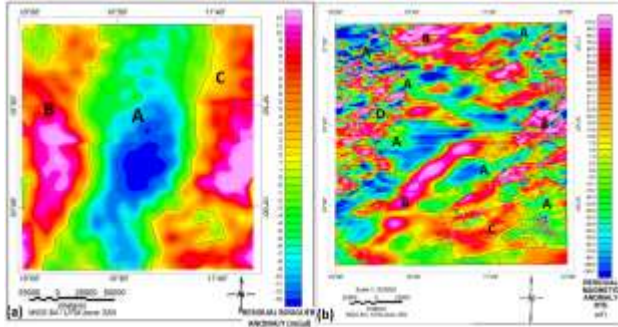


Figure 2. Residual Map of (a) Bouguer Anomaly (b) Magnetic Anomaly Reduced to the Equator

4.3 SPI Analysis

The result of the SPI analysis for both the gravity and aeromagnetic survey is presented in the sub section below.

4.3.1 Bouguer Gravity

The SPI map in Figure 3a reveals an approximate maximum depth of 9826 m occurring as pockets with pink colour within the Map. The derived map highlights the spatial location of various gravity sources at different depths from the surface. A least depth of less than 1798 m was observed. A general partial South-west to north-east trend of deeper sources was ascertained. The areas illustrated by red colour (7703 m) and pink colour (9826 m) were the regions of deeper sources. The intermediate depth was depicted in blue-green colour (2275 m) and yellow colour (5779 m). The deeper and intermediate classes with depth (>4000 m) are the potential regions that oil and gas maturation can take place. The shallow sources illustrated in deep blue colour are below 1798 m are the least dominant features on the map, these are the regions that might house mineral resources.

4.3.2 Aeromagnetic

The SPI map in Figure 3b reveals an approximate maximum depth of 8913 m occurring as anomalies with pink pigments within the Map. A least depth of 1362 m based on the colour scale was also noted. The Map was broadly categorized into three major classes of deep and shallow regions. The general South-west to north-east trend of deeper sources indicates the sedimentary cover overlain above the basement because of geodynamic events. These areas are illustrated as high on the legend with depths ranging

from 5414 m to approximately 8913 m. They can also be characterized by a deeper source associated with basin graben Structure. The intermediate category starts at a depth of 1898 m (yellow colour) to 4599 m (red colour). As is the case with the gravity survey, a depth above 4000 m has the potential for oil and gas maturation. The shallow depth depicted as blue-green colour with depth ranging below 1772 m were dominant at the extreme West and Eastern parts of the map. This second class can be geologically associated with the basin uplift or horst structure. The horst and graben structure observed is one of the structures that harbours oil and gas. The SPI map strongly correlates with the regional geologic settings of the study area which shows the sedimentary basin surrounded by basement rocks from both sides and few basic rock intrusions scattered across. Similar to the gravity survey, the horst up lift and other shallow sources are potential targets for orogenic minerals.

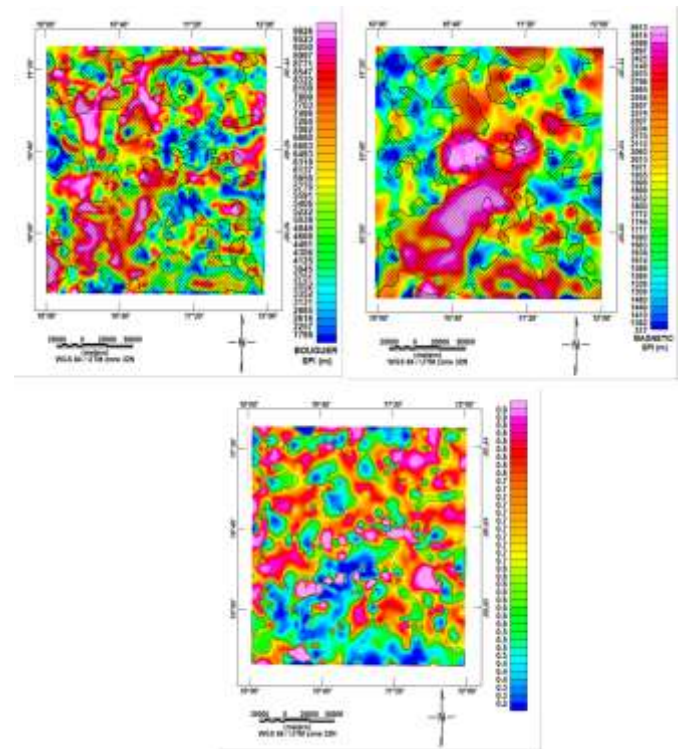


Figure 3. SPI and Error Plots (a) Gravity (b) Magnetic (c) Error

4.5 Error Analysis

The analysis of error reveals the relationship between the gravity and magnetic SPI depths. Figure (3c) shows the normalized absolute error of the superimposed gravity and magnetic SPI. The colour scale bar in Figure (3c) shows a range of 0.2 (deep blue color) to 0.9 (pink color). The color legend bar can be categorised into 3 zones. The first category captured a range of blue to light green color corresponding to a normalized value of less than 0.6. This is the best portion with the highest precision. This category also corresponds to the majority of deeper anomalies in the gravity Figure (3a) and magnetic Figure (3b) SPI maps. The second category blends in with the third category by engulfing it. The second category ranges from above 0.6 (pale yellow) to 0.7 (light orange) representing a transition between category 1 to category 3. It is the zone of moderate precision. The third category has a value above 0.7 (orange) on the colour bar. It represents the zones of least precision. Therefore, it is recommended to give more emphases to the zones with high precisions for inferring the various depths associated with potential field sources which may contain valuable resources.

CONCLUSION

The investigation of depth to gravity and magnetic source carried out over the Gongola basin part of the Upper Benue Trough, Nigeria using both source parameter imaging and spectral analysis yields promising results. The result of the adopted methods for SPI were in very close agreement with each other having a depth to deep sources of 9826 m and 8913 m), intermediate sources (5779 m and 4599 m) and shallow sources (below 1798 m and 1772 m). Depth above 4000 m were recommended for further oil and gas investigations while sources closer to the ground were recommended for mineral investigation.

Therefore, this research provides precise information on the depth configuration of Gongola basin that might yield mineral oil or gas. It also serves as a guide to other researchers to build a confident interpretation of the subsurface through complementing methods. To further explore the basin, a detailed modelling is recommended.

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