RESEARCH ARTICLE

DELINEATION OF FAULTS AND CAVITIES USING GRAVITY TECHNIQUES: AN IMPLICATION FOR ROAD CONSTRUCTION, SOUTH-SOUTH NIGERIA

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ARTICLE DETAILS

ABSTRACT

This study was carried out using five digitized aerogravity data to delineate near-surface structural faults, cavities, low-density zones and estimate the mass balance unit in foundations. Qualitative and quantitative analysis were performed in order to examines the depths to anomalous bodies, density/mass and stratigraphic features such as faults and cavities. The techniques employed were: Source parameter imaging (SPI), 3D Euler deconvolution, forward and inverse modeling. The results of the SPI shallow values range from -5.62 to -53.74 m and deep values range from 3.33 to 120 m. The 3D Euler deconvolution results range from -1892.2 to -1278.3 m for obscure and -12264 to 644.6 m for superficial formations. The forward and inverse modeling result shows the values of depth ranging from 2.5 to 4.8 km, density/mass range from $(0.7$ to $2.4)$ x 10^{-3} kg/m^3 and $(27$ to $133)$ x 10^{10} kg of three profiles which is the parameter contrast of the gravity surveys. This shows sequential depths and density/mass contrast between the body of interest and the surrounding material which depicts the presents of faults, sedimentary basins and rock bearing minerals of shale/marble which comprises of air, water and sediment-filled formations. The information from this study has revealed the true nature of the subsurface and this will serve as a guide during road construction.

KEYWORDS

microgravity, aerogravity, SPI, Euler deconvolution, sedimentary basin.

1. INTRODUCTION

Roads are essential channels of transportation that need to be build and sustained in order to fast track mineral and economic development, such as roads in the south-south region of the country where heavy rainfall dominates throughout the year. There is need for proper knowledge of subsurface information before undergoing road constructions. However, it is necessary to employ geophysical techniques that would provide information about the lithology and stratigraphy of the subsurface formation (Obiora et al., 2016). Numerous construction and rehabilitation projects such as; infrastructural development of new and expansion of the existing infrastructural projects are ongoing. It is essential to be very careful in the planning of roads in order to avoid direct impacts such as excessive costs, energy and time, or indirect costs such as environmental and ecological impacts.

Furthermore, in most cases the main reasons for project delays is due to unsatisfactory project planning with regards to conditions in subsurface material, bedrock and groundwater levels (Ezekiel et al., 2013; Sharma, 2013). Different subsurface materials can cause local disturbances in the Earth's natural fields which can be detected with sensitive instruments (Obiora et al., 2015; Oha et al., 2016; Ekpa et al., 2020). Some geological factors such as clayey subgrade soil below the road pavement, lateral inhomogeneity, near surface geological structures and changes in elevations due to fluctuation in the saturated zone are responsible for the susceptibility of the roads to failure (Adesola et al., 2017). Geophysical methods can be classified as passive and active methods, passive method measures the variations in natural fields of earth such as; magnetic and gravitational fields whereas active method makes use of artificially generated fields such as electrical and seismic signal.

Active methods have been used by some researchers within the study area to investigate the subsurface, in which artificial signals (energy) were generated, and the results help in determining the soil water and compaction state (Reynold, 2011; Mandal et al., 2015, Aka et al., 2018 and 2013; Okiwelu et al., 2013). However active methods used did not give clearer information due to anomalies such as; high levels of electrical and acoustic noise encountered from public facilities leading to errors in the results, volume of material being sampled and resolution desired. Gravity technique investigates changes in the subsurface density/mass variations in the earth's gravitational field. It is distinctly capable of delineating the subsurface faults, cavities and mapping of geological boundaries, lineaments, dykes and layered complexes which may have influence on the overlying sediments (Ekpa et al., 2020).

Hence, the current research therefore employed aerogravity (a reconnaissance survey) which can be use in high level noise terrains with valuable data for large area with greater depths. These delineate cavities and faults; identify areas with varying density/mass bedrock type and minimize stress and manpower (Milsom, 2003). The aerogravity data are acquired with sufficient resolution which contributes towards resource-scale projects which can be used to characterize salt domes for petroleum exploration, monitoring of geothermal reservoirs under exploitation, inferring location of faults, and permeable areas for hydrothermal movement. This method can be used for shallow engineering applications such as; road design, constructions and maintenance phases. The unit of measurement used in the gravity method is the Gal (in honor of Galileo), typical gravity surveys for environmental and engineering applications require measurements with an accuracy of a few µGals (10^{-6} Gals), which is referred to as microgravity surveys (Hunt et al., 1995).

On the other hand, it is necessary to collect data about the area before construction in order to calculate the amount of cut and fill required, materials available and materials which need to be transported to the site. By doing this, we can obtain information regarding the surface and subsurface condition of an area such as; cavities, structural anomalies (faults) and bedrock types using geophysical methods (Benson, 2000; Biswas et al., 2017). The objectives of this study are to delineate near-surface structural faults, cavities, low-density zones and determination of materials balance in foundations.

2. LOCATION AND GEOLOGY OF THE STUDY AREA

The study area is located on the continental margin of the Gulf of Guinea, otherwise called Niger Delta formed in the Paleocene (Figure 1). The region is fed with sediments from the Niger River with an extensional rift basin, where rifting occurred from the Late Jurassic to the Late Cretaceous (Okiwelu et al., 2013; Aka et al., 2018). Cretaceous fracture zones, expressed as trenches and ridges, control the tectonic framework of the delta and separate the margin into individual sub-basins, which form the boundary faults of the Cretaceous Benue to Abakaliki trough. As the delta progrades, growth to fault bounded depobelts are created such as: the northern delta, central delta and the distal delta province. Three large scale lithostratigraphic units extend across the tertiary delta, each range in age from early Tertiary to Recent and distinguished from one another on the basis of their sand to shale ratios. These units are related to outcrops and environmental deposition (Mickus, 2004). It comprises of; upper sandy Benin formation, intervening unit of alternating sandstone/shale Agbada formation and a lower shaly Akata formation.

Akata formation underlies the entire base of the delta. It is composed of marine pro-delta shales and turbidite sands with minor amounts of clay and silt depositions of about 7,000 m thick since the Paleocene. Agbada formation overlies the Akata formation, it contains paralic siliciclastics and is considered to be the main deltaic sequence with most economically exploitable hydrocarbon in the region. The formation lies approximately 930 m below sea level at the base of freshwater sands (Lehmann et al., 2009; Telford, 1990). Also, the base of the formation lies 2480 m below sea level thickens towards the offshore. Benin Formation overlies the Agbada formation, composed of fluvial and upper coastal plain facies that has been deposited since the Oligocene and extends across the entire delta. It is consisting of sands that are up to 2000 m thick in the delta (Okiwelu et al., 2013). The delta subsurface structures are described as resulting from movement under the influence of gravity and their distribution is related to growth stages of the delta.
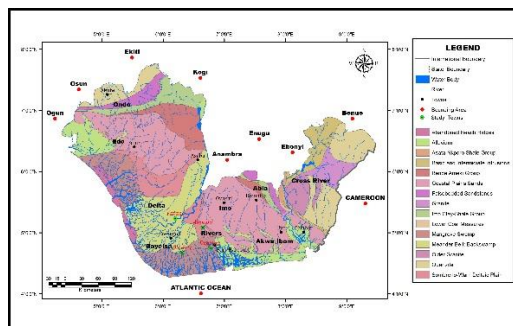

Figure 1: Map of Nigeria showing the region of the study area

2.1 Data Acquisition

Fugro airborne surveys carried out the airborne geophysical surveys overseen by the Nigerian Geological Survey Agency (NGSA). Five digitized aerogravity sheets were obtained from Nigerian Geological Survey Agency in XYZ Geosoft format. X and Y were the distance in meters and Z is the Bouguer anomaly measured in miligal. The five sheets were gridded into twenty-five blocks for proper delineation of structural trends such as faults and depth.

2.2 Data processing

Digitized airborne gravity data was uploaded into Oasis Montaj software using database tools menu button in the software. The first step was the gridding of the data set to enhance better resolution and imaging. By gridding, it means interpolating data into equally spaced cells co-ordinate system. These frameworks generate robust applications avail to produce 3D Bouguer gravity of the study area by employing minimum curvature algorithm method. The second step was the interpretation of bouguer gravity map; qualitatively and quantitatively in order to delineate faults, cavities and depths of gravity anomalous bodies. In qualitative interpretation, subsurface structures examine the grid of gravity anomalies, contours maps and gravity profiles to determine the lateral location of spatial gravity variations.

This depicts fragmented fractures, cavities and faults patterns as well as groundwater level fluctuation. The quantitative interpretation quantified the anomaly of interest from the remaining background anomaly and modeled to determine the depth, density and geometry of the anomaly's source. These was done using three techniques namely; source parameter imaging (SPI), 3D Euler Deconvolution, forward and inverse modeling to enhance a better understanding of the subsurface. (Biswas et al., 2017). SPI is an image formed from potential field's depth and local wavenumber of the observed field at any gridded data point through horizontal and vertical derivations (Eletta and Udensi, 2012). It analyses the properties from the local wavenumber; first and second orders deriving analytic signal responses. It is expressed as shown in Eqns. 1 - 4 respectively.

$$A_1(x,z) = \frac{\partial M(x,z)}{\partial x} - j\frac{\partial M(x,z)}{\partial z} \qquad (1)$$

$$K_1 = \frac{\partial}{\partial x}tan^{-1}\left[\frac{\partial M}{\partial z} / \frac{\partial M}{\partial X}\right] \qquad (2)$$

$$A_2(x,z) = \frac{\partial^2 M(x,z)}{\partial z\,\partial x} - j\frac{\partial^2 M(x,z)}{\partial^2 z} \qquad (3)$$

$$K_2 = \frac{\partial}{\partial x}tan^{-1}\left[\frac{\partial^2 M}{\partial^2 Z} / \frac{\partial^2 M}{\partial X\partial X}\right] \qquad (4)$$

Where M(x,z) is the magnitude of gravitational field in x and z Cartesian coordinates for vertical and horizontal directions. J is the imaginary number, $A_1(x,z)$ and $A_2(x,z)$ is the first and second order analytical signals. K_1 and K_2 is the first and second local wavenumber model and depth estimations (Biswas et al., 2017). Euler deconvolution is an inversion technique that reflects the source locations and depth boundary of underground anomalous sources (Maden, 2010). 3D Euler equations relate gravity field and gravity gradient tensor with structure index. It is expressed as shown in equation 5 and 6.

$$V_{x\,(x-x_0)} + V_{y\,(y-y_0)} + V_{z\,(z-z_0)} = -N\,[V(x,y,z) - B] \qquad (5)$$

$$\frac{\partial V_\alpha}{\partial x}(x - x_0) + \frac{\partial V_\alpha}{\partial y}(y - y_0) + \frac{\partial V_\alpha}{\partial z}(z - z_0) = -(N+1)(V_\alpha - B_\alpha) \qquad (6)$$

Where x, y, z are gravity anomaly of point x_0, y_0 and z_0, v is the gravity field, B is the base level of observed field and N is the structure index, and V_α is the gravity gradient tensor. The forward and reverse modeling is the final step in processing potential field data in order to determine the density, depth and geometry of the anomalous bodies. In forward and reverse modeling, iterative methods were employed using potent 3D tools of Oasis Montai software, where the calculated and observed field data were compared (Nwankwo et al., 2011). In order to have a deemed close match and improve fitting between the calculated and observed anomalies.

3. RESULTS AND DISCUSSION

Source Parameter Imaging (SPI), Euler Deconvolution, forward and reverse modeling were adopted for delineating structural trends and cavities. In qualitative analysis, 25 gridded data blocks of SPI were merged together, contour maps and gravity profile were done to determine the spatial variations in earth's gravitational field. Quantitative analysis examines; depths and thicknesses of the layers, density and mass, structural trends and stratigraphic features such as faults, syncline and anticlines and unconformities that causes the gravity field variations. Figure 2 shows 25 gridded data block of aerogravity SPI map. The analysis presents offshoots parallel/ perpendicular flow banding from shallowest

to deepest anomalous gravity bodies. The shallowest values range from -5.62 to -53.74 m, the negative value delineates invasive. The deepest values range from 3.33 to 120 m respectively. Low depth values portray loose sediment formation, whereas, high depth portray dense sediment formation indicating hydrocarbon mass (Obiora eta al., 2016).

On the other hand, bouguer gravity anomaly values range from -15.5 to 35.2 m, in which the negative values indicate low compactness disparity of gravity. Thus, the positive values indicate areas with high density/mass of the underlying rocks. Figure 3 shows 3D surface map with deepest sedimentary thickness at north-eastern region, shallowest sedimentary thickness and depression at the south-eastern part. Fig. 4 shows the structural trend map derived from the bouguer gravity data. The map was offshoot perpendicular and parallel which depict the presence of faults lines on the lineament map showing the minerals and rocks bearing zones of the region. It is necessary to separate the anomaly of interest; that is the residual anomaly, from the remaining background anomaly which is the regional anomaly by involving the 3D tools mathematical operations of Oasis montaj. Therefore, the residual anomaly was modeled to determine the depth, density and geometry of the anomaly source using 3D Euler Deconvolution in x, y and z vertical offshoot of three index numbers; 0,1 and 2.

The index numbers imaging reflects the geological structure of the region and the Euler map as shown in Fig.5 with different colour formations. The light green to pink colors shows areas with superficial gravity anomalous bodies while the aqua to blue colors shows obscure anomalous gravity bodies. The results range from -1892.2 to -1278.3 m for obscure and -12264 to 644.6 m for superficial formations of basic indication. The final step involves the forward and inverse modeling to determine the density/mass of the subsurface using residual gravity anomaly. This shows sequential dimensions of the density contrast between the body of interest and the surrounding material. The techniques involve was iterative modeling, where the earth's gravitational field due to the models is calculated and compared to the observed gravity anomalies. This was done in three profiles for easily matching between the calculated and the observed anomalies.

However, Fig. 6 shows a contour map with highest value of 3.4 m at the northern region and lowest value of 1.8 at the southern region with three profiling of; P1, P2 and P3. The profiling depicts three colors (blue, pink and gray) with cylindrical and ellipsoidal shapes, indicating accumulations of shale, petroleum and kaolinite as possible cause of gravity anomalies as shown in Fig.7. The modeling descriptions of cylindrical and ellipsoidal were used to deduce the structural pattern in the region as shown in Table 1. The table shows low gravity values attributed to anticline structural trends, high gravity values attributed to syncline structural trends. The forward and inverse modeling depth values range from 2.5 to 4.8 km with corresponding density and mass values ranging from (0.7 to 2.4) x 10^{-3} kg/m^3 and (27 to 133) x 10^{10} kg respectively. These density and mass values depicts the presents of strike-slip and normal faults with natural cavities of air, water and sediments-filled formations (Hunt et al., 1995). These sediments filled formations with poor engineering geo-materials has to be removed in order to avoid engineering problem and refilled with good competent and rock quality formations which could enhance planning and construction of good roads.
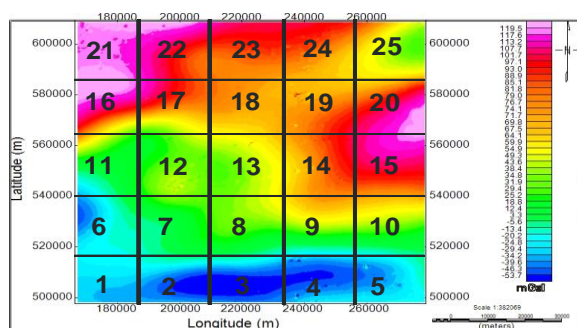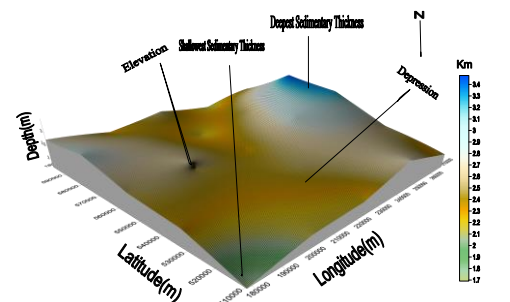

Figure 3: 3D map of depth gravity sources showing sedimentary topography
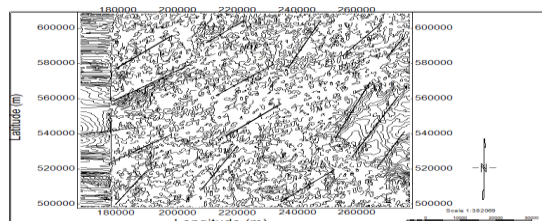

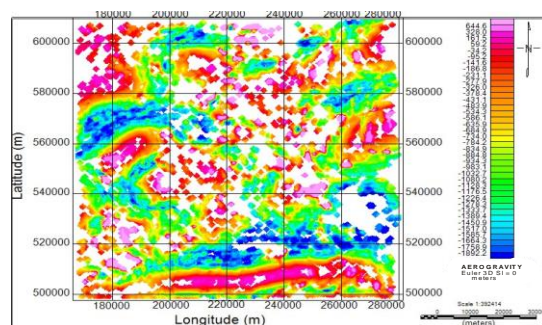Figure 4: Structural trends map showing the lines of faults in the study area

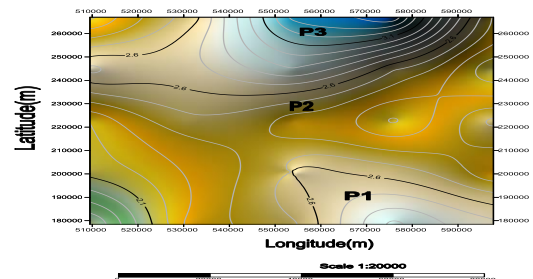Figure 5: 3D Aerogravity Euler depth map
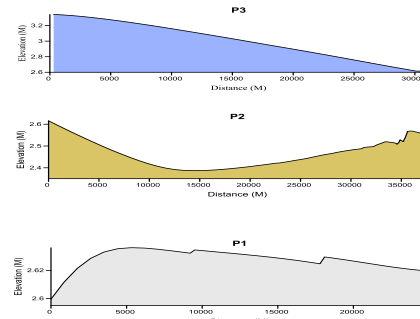

Figure 6: Contour map showing gravity profiles

Figure 7: Profile trends of gravity anomaly

Figure 2: 3D Gridded data point for SPI analysis

| Table 1: Structural stratigraphy trends, depths and density of modeling							
Profiles	Model Patterns	Structural Patterns	Depths (km)	Density Contrast (10^{-3} kg/m^3)	Faults	Cavities	Gravity anomaly Causes
P1	Cylindrical	Syncline	2.5	2.4	Strike-slip	Natural	Kaoline
P2	Cylindrical	Anticline	3.9	1.8	Strike- slip	Natural	Shale
P3	Ellipsoidal	Anticline	4.8	0.7	Normal	Natural	Petroleum
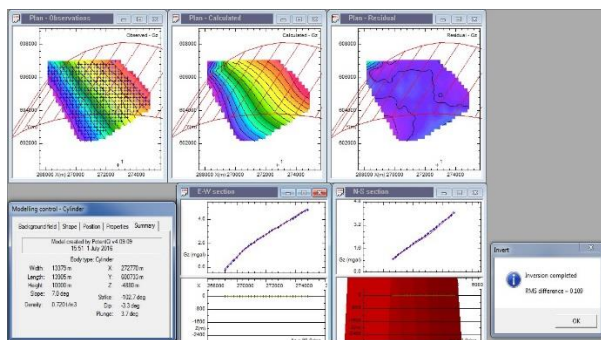
Figure 8: 3D forward and inverse modeling profiles

4. CONCLUSION

Aerogravity data has been used to delineate faults and cavities using gravity techniques in order to aid in better roads construction. Gravity techniques depict clearer information with regards to the presence of subsurface faults and cavities and identify possible gravity sources. However, the presence of negative anomalies indicates natural cavities that pose menace to ground bearing capacity in engineering constructions, due to decreased density contrast caused by rock fracture with possible calculation of depths of anomalies. From the results, bouguer gravity anomaly values, both shallow and deep depths were delineated in which the negative values indicate low compactness of gravity. Also, low depth portrays loose sediments formation whereas high depth portray dense sediment formation indicating hydrocarbon mass. Three profile were made showing cylindrical and ellipsoidal model patterns with syncline and anticline structure trends. These density/mass assess depicts the presents of strike-slip and normal faults with natural cavities of air, water and sediments-filled formations, indicating accumulations of shale, petroleum and kaolinite as possible cause of gravity anomalies within the study area.

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