DETECTION OF LITHOLOGICAL BOUNDARIES USING SECOND ORDER VERTICAL DERIVATIVES OF AEROGRAVITY DATA; A CASE OF HADEJIA SEGMENT OF THE CHAD BASIN, JIGAWA STATE NIGERIA

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ABSTRACT

Gravity method of geophysical prospecting is very effective in delineating geologic formations of based on the formation's density contrast. In this work, a second vertical derivative of gravity data was used to delineate the boundary between two geologic formations of significant contrast in formation density. The study area is within the Hadejia arm of the contact region between the Chad sedimentary formation and the crystalline basement complex in the Northeastern Jigawa state of northern Nigeria. Satellite gravity data of the area which lies between latitude 11^0 -13^0E and longitude 8^0 - 14^0N was obtained from Bureau Gravimetrique International (BGI). The Bouguer correction was already applied on the data. Bouguer graph was plotted using surfer software. Second vertical derivative graph was also plotted. Low gravity anomalies are observed in the north with its minimum value appearing in the southwest**.** This suggests the existence of sedimentary rocks which are low in density, since sedimentary rocks are characterized by low density values. The result shows that second vertical derivative method is suitable for enhancing weaker local anomalies, defining the edges of geologically anomalous density disseminations and identification of geologic units.

Keywords: Gravity Data, Second vertical derivative, Boundary, Hadejia, Chad basin

INTRODUCTION

The application of various geophysical techniques in characterizing physical properties of the earth provides information about subsurface. It aids in the classification of the geology of the subsurface and imaging of its mineral and energy resources. Geophysicists measure properties of rock such as density, magnetic property, elastic moduli, radioactivity which are used to infer rock type and mineral composition of the rock. Gravity method is among the geophysical methods commonly used in environmental, engineering, archaeological and other sub-surface investigations. Progresses made in observation, processing and analysis of data due to technological advancement have made gravity method efficient, sensitive and more applicable to wider range of problems (Justia et al,2018).

Gravity method measures difference in earth's gravitational field at different locations using an instrument known as the gravimeter. Gravity anomalies are computed by subtracting regional field from the measured field. The gravitational field strength is directly proportional to the density of subsurface materials. This gives gravity anomalies that correlate with source body density variations. (Justia et al, 2018). Positive gravity anomalies are associated with shallow high density bodies while negative anomalies are associated with low density bodies.

The gravity method is based on the principle of Newton's law of universal gravitation and Newton's law of motion. (Ofoha et al, 2018). The Newton's law of universal gravitation states that "the force of attraction between two bodies of known masses is directly proportional to the product of their masses and inversely proportional to the square of the distance between their centers of mass". This can be expressed as

$$F = G\frac{m_1 m_2}{R^2} \quad (1)$$

where

F is the = the force of attraction between two of the masses,

G is the Universal gravitation constant

m_1 and m_2 are the masses of the bodies,

R is the separation between the two masses

Newton's second law of motion states that "the rate of change of momentum of a body, is directly proportional to the force applied and this change in momentum takes place in the direction of the applied force. In other words, Newton's second law of motion can be stated as "In an inertial reference frame, the vector sum of the forces F, on an object is equal to the mass m of that object multiplied by the acceleration, a, of the object" Newton's second law, the force of attraction F on a body of mass m due to the gravitational acceleration g is given by

$$F = mg \quad (2)$$

This can be expressed in differential form as (Ofoha et al, 2018) as the rate of change in momentum *dp/dt*. That is

$$F = \frac{dp}{dt} \quad (3)$$

The universal gravitational law, according to Newton, the essential characteristics of the gravity method can be explained in terms of mass and acceleration as illustrated in Newton's second law. The mass distribution and shape of an object are linked by the objects center of mass. (Justia et al,2018) (Ofoha et al, 2018). Equating (1) and (2) implies that

$$g = G\frac{m}{R^2} \quad (4)$$

The gravitational potential at a point due to the earth's gravitational field is the work done by the attractive force of the earth Mg on m as it moves from 0 to infinity. The concept of the gravitational potential helps in simplifying and analyzing certain kinds of force fields like gravity, magnetic and electric fields. Thus the work necessary to move the unit mass a distance in the direction of r is given by

$$V = GM\int_{\infty}^{R}\frac{dr}{r^2} = G\frac{M}{r} \quad (5)$$

The gravity anomaly is linear with density contrast so other density contrasts can be evaluated by scaling the given curves. For an infinite slab model, the gravity contrast is given in term of the density contrast $\Delta\rho$ as

$$\partial g_B = 2\pi G\Delta\rho h \quad (6)$$

Where h is the thickness of the slab.

The gravity anomaly is the difference in values of the actual earth gravity g_F (gravity observed in the field) with the value of the theoretical homogeneous gravity model ∂g_B in a particular reference datum.(Justia *et al*, 2018). That is

$$g_B = g_F - \partial g_B \quad (7)$$

Previously, authors determined the density value at research locations using the Parasnis method.(Paranis, 1952). Parasnis's method is based on the statement that the bouguer anomaly can be expressed as an equation of the form of "y = mx + b" that is

$$g_{obs} - g_N + 0.3086h = (0.04193h\text{-}TC)p + BA \quad (8)$$

The final form of the processed gravity data can be used in many types of engineering and environmental problems like detection of subsurface voids including caves, adits, mine shafts, (Georg *et al*, 2011) determining the amount of subsidence in surface collapse features over time, (Setyawan *et al.*, 2015) soil and glacier sediment thickness (bedrock topography) (Salimi, 2012) , groundwater volume and changes in water table levels over time in alluvial basins, (Smith *et al.*, 2005) mapping the volume and location of buried sediment valleys, (Barnaba *et al*., 2010) lateral and vertical extent of landfills, mapping steeply dipping contacts including faults,determining the location of unexploded ordinances (keary*et al.,* 2002).

One of the essential components in potential field data interpretation is edge detection. Edge detection filters enhance edges of anomalies and make them more visible (Blakely and Simpson, 1986), so many filters were used to perform this task (Hosseini *et al.*, 2013).In this paper, we applied second vertical derivative on aero gravity data to detect the edges of geologic contact associated with two different geologic formations in the western end of the Chad Basin. The study area is a contact zone between the sedimentary basin of the Chad Formation and the cretaceous crystalline basement complex of northern Nigeria.

The Study Area

Hadejia Local Government lies on the north eastern part of Jigawa State latitude 12^0 13' and 13^0 60'N and longitude 9^0 22'– $11^0$00E. The area is underlain by rock and younger sediments of the Chad formation. The climate of the area is semi-arid. It is characterized by a long dry season and a short wet season from June to September. The average annual temperature is 27.2^{o}C, while the total annual rainfall ranges from 600mm to 762mm, the regional vegetation falls within the Sudan Savannah type with extensive open grassland with few scattered trees. (Ekanem *et al.,* 2016). Figure 1 shows the location of the study area.

Geology of the Area

The area is underlain by rock and younger sediments of the Chad formation. Approximately 10% of Chad Basin is occupied by Nigeria in the middle of latitude 11^{o}N and 13^{o}45’38’’N and longitudes 8^{o}21’49’’ and 14^o 40’22’’E in North central part of Nigeria (kwaya *et al* 2018). The Chad Basin lies within a vast area of Central and West Africa at an elevation of between 200 and 500m above sea level and covering 230,000 km^2. The basin has been referred to as an interior sag basin, due to a sagging episode that has affected it before the onset of continental separation during which a rift system junction was formed providing appropriate site for sedimentation. Therefore, it lies at the junction of basins (comprising the West African rift) which becomes active in the early Cretaceous when Gondwana started to split up into component plates. Sediments are mainly continental, sparsely fossiliferous, poorly sorted, and medium to coarse grained, feldspathic sandstones called the Bima Sandstone. Both geophysical and geological interpretations of data suggest a complex series of Cretaceous grabens extending from the Benue Trough to the southwest. (Nwankwo *et al* 2012).

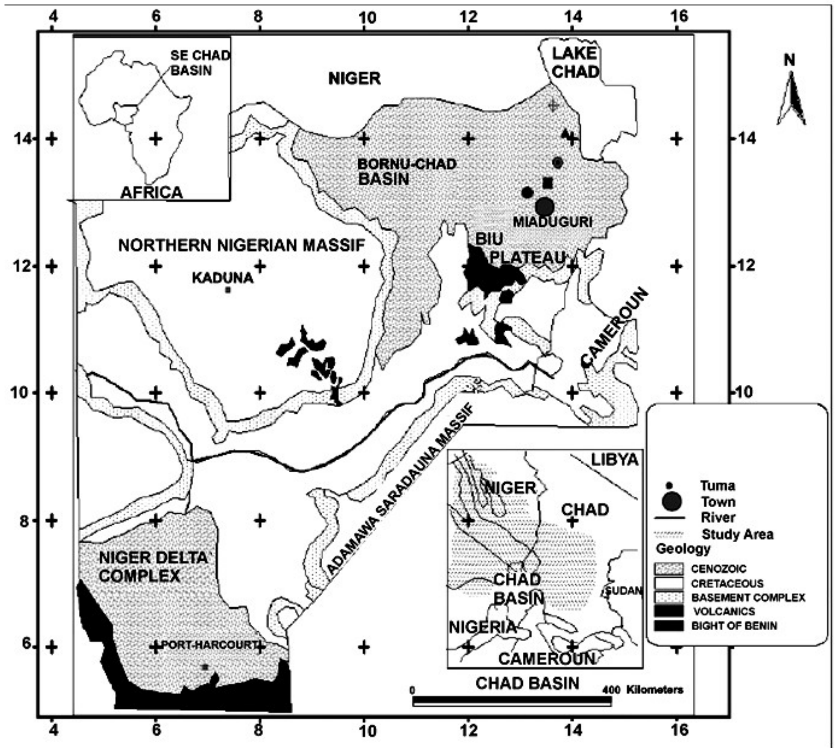

Figure 1: Nigerian map showing chad basin area.

MATERIALS AND METHODS

The data used is the satellite gravity data of part of Nigerian Chad basin which lie between latitude 11^0 -13^0E and longitude 8^0 - 14^0N. It was obtained from Bureau Gravimetrique International (BGI) whose survey was carried out in conjunction with IAG International Gravity Field Service. Determination of the gravity field of the earth from space involves measuring the height of a satellite above sea level by radar altimetry. A series of satellites has been used such as Skylab, GEOS3, SEASAT, Geosat, ERS1,and ERS2 (Foulger and Peirce, 2007). SEASAT is the one used by BGI to obtain the Data in use.
SEASAT was launched in 1978 into a circular orbit with an altitude of 800km. It circled the earth each day 14 times and covered 95% of the earth's surface every 36 hours. The position of SEASAT in three dimensions was continually monitored by laser sites whose coordinates with respect to the spheroid are known. The satellite continually transmit radar signal which bounced off the sea surface. The two way travel time was measured and the values are used to find height and then the value of the acceleration due to gravity.
The second vertical derivative (SVD) of gravity data can be used to delineate the boundaries of anomalous sources. The derivative places tends to emphasize on local anomalies and isolate them from local background. (Aku, 2014). The calculation of gradients is anticipated to boost subtle features of gravity data that otherwise cannot be visually noticed from the original data. (Sumintadireja *et al*, 2018) High gradients can be associated with a high contrast of physical properties of the subsurface and vice-versa. Gradients, and also their magnitude, are usually employed to delineate boundaries of anomalous sources. The SVD of the vertical component of gravity, g_z, can be calculated in the spatial domain from the horizontal gradients by using the Laplace's Equation (Putra et al, 2019)

$$\frac{\partial^2 g_z}{\partial z^2} = -\left(\frac{\partial^2 g_z}{\partial x^2} + \frac{\partial^2 g_z}{\partial y^2}\right) \quad (9)$$

For an elongated anomaly along the *y*-axis, the SVD can be approximated by the second horizontal derivative of the gravity data along the *x*-axis (Sumintadireja et al, 2018) as

$$\frac{\partial^2 g_z}{\partial z^2} \approx -\frac{\partial^2 g_z}{\partial x^2} \quad (10)$$

In the wave-number domain, or Fourier domain, the SVD is usually calculated by the equation (Sumintadireja et al, 2018)

$$\frac{\partial^2 g_z}{\partial z^2} = F^{-1}(|k|^2 G_z) \text{ with } |k|^2 = k_x^2 + k_y^2 \quad (11)$$

The svd mad was also plotted from the bouguer map using the same software.

RESULTS

The data was obtained from Bureu Gravimetric International (BGI). The data was corrected for Bouguer, leading Bouguer anomaly data. It was then converted from excel to dat file. It was gridded using surfer software and subsequently the contour map was plotted using the same software. Fig. 2 below shows the contour map of the study area which reflects the Bouguer gravity anomaly map.

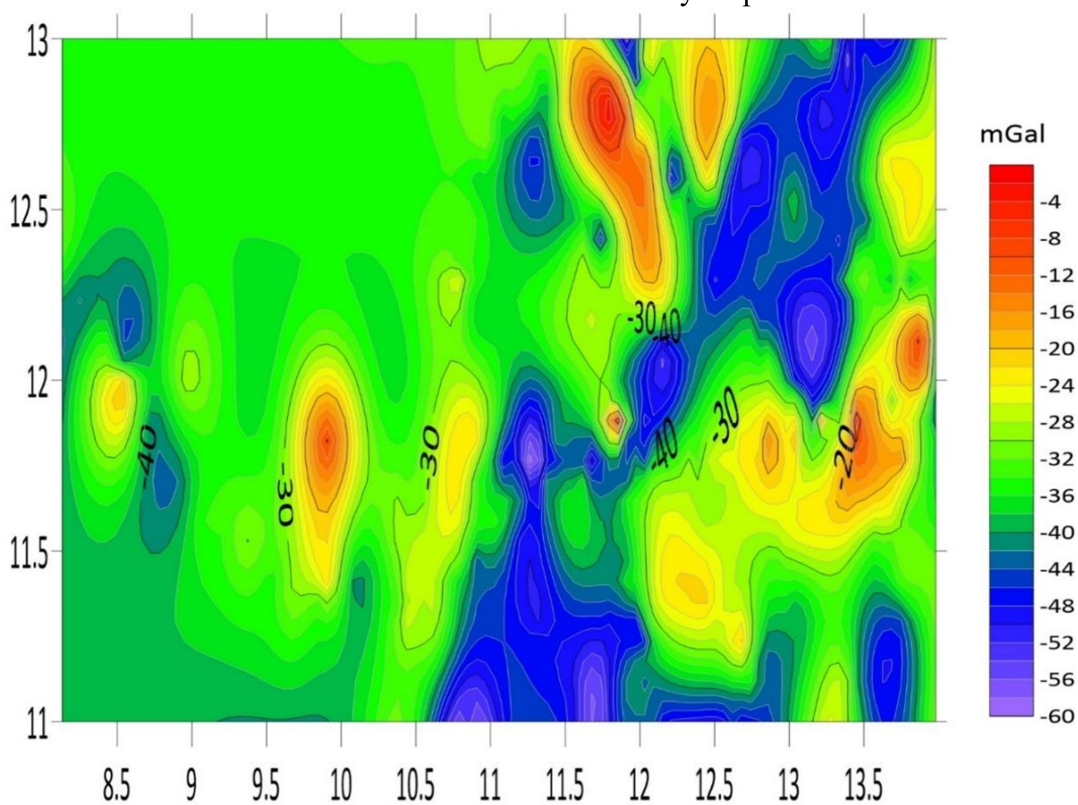

Figure 2: Bouguer gravity map

The bouguer data was then filtered using second vertical derivative on surfer software to produce a the SVD contour map as shown in Fig. 3

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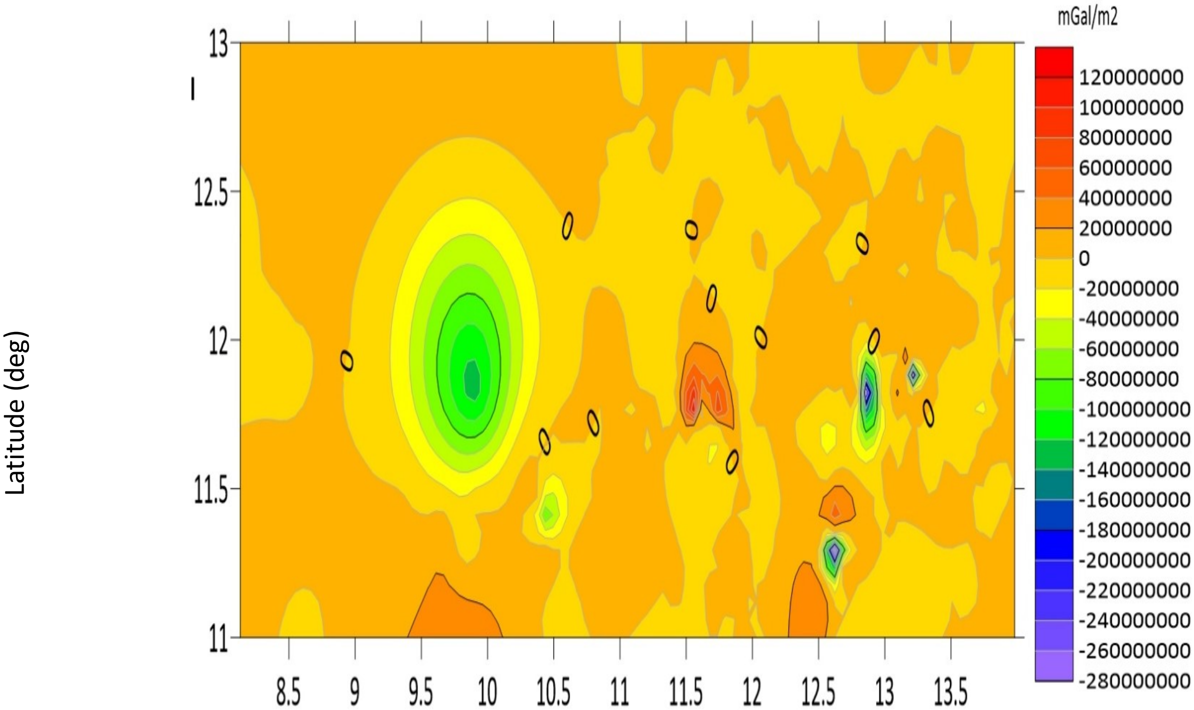

Figure 3: SVD graph showing zero edges

DISCUSSION

The Bouguer gravity anomaly map (Fig. 2) indicates that the Bouguer anomaly of the study area varies from – 58mGal to − 2 mGal. The negative sign shows that the area is typically occupied by materials that have low density value. Low gravity anomalies are observed in the map with its minimum value appearing in around 11.5-11.7N, 11.0-11.2E and 11.2-11.33N, 11.69-11.85E. This indicates that there is existence of sedimentary rocks because sedimentary rocks are characterized by low density values (Akiishi et al, 2019). Meanwhile, Bouguer gravity anomalies are maximum around 11.70-11.80N, 12.73-12.84E.

The Second Vertical Derivative map in Figure 3 shows that the 'polarity' of the anomaly can still be recognized. That is the low density rocks are in the central part relative to its surroundings. The map of second vertical derivative method in this study shows that it is useful in enhancing weaker local anomalies, defining the edges of geologically anomalous density distributions and identification of geologic units. The map produced extended zero contours which corresponds to the edges of local geologically anomalous density distributions structures. The quantity zero remarkably coincides with most of the lithological boundaries when compared with the major geologic contacts.

CONCLUSION

Several mineral resources of economic importance are formed within contact zones, fractured or shear zones and intrusive bodies (Hinson *et al*., 2015). This work demonstrates the significance aerogravity survey in delineating the boundaries between the basement structures connected with known deposit and the sedimentary formation of the study area. The importance of the second vertical derivative arises from the fact that double differentiation with respect to depth tends to emphasize on the smaller, shallower geologic anomalies at the expense of larger regional features. The second vertical derivative image is thus often seen as a perfect and better resolved image of the type of anomalies which are significant in oil and gas or mineral exploration than in the gravity image. The second vertical derivative enhanced the shallower effects at the expense of deeper effects to completely remove the regional effects to determine the sense of contacts. Further research on the area is therefore recommended for more geophysical researches to further investigate the mineralogy of the area. This will help to add certainty of finding the expected resources prior to exploitation.

Acknowledgement

We acknowledge the effort of National Geospatial-Intelligence Agency (NGA) and Bureau Gravimetric International (BGI) for compiling and making available the dataset used in this work.

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