https://dx.doi.org/10.4314/dujopas.v7i4b.10
ISSN (Print): 2476-8316
ISSN (Online): 2635-3490
Dutse Journal of Pure and Applied Sciences (DUJOPAS), *Vol. 7 No. 4b December 2021*

Interpretation of Gravity Data of Hadejia and Its Environs Using Tilt Angle Derivative Method

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Abstract

Tilt angle derivative method was applied to satellite gravity data of Hadejia and surrounding for subsurface delineation. The study area falls in the contact region between Chad sedimentary formation and the crystalline basement complex in the Northeastern Jigawa state and Northwestern Yobe state of Nigeria which lies between latitude 8^0N - 14^0N and longitude 11^0E -13^0E. Satellite gravity data of the area was obtained from Bureau Gravimetrique International (BGI). The Bouguer correction was already applied on the data and the Bouguer graph was plotted using surfer software. Low gravity anomalies are detected in the dominant part of the map with its minimum value appearing in the south-eastern and north-eastern part of the map. The low anomalies are probably due to existence of thick sedimentary sections in these parts of the study area. Edges and Depth of the source of anomaly were also derived from the tilt angle. The tilt angle ranges between -3.5 degrees to 3.5 degrees with edges(boundary) at zero. This describes the edges/boundaries between the two formations. The method also revealed that the

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area has a depth ranging between 2km to 18km. The sedimentary areas were identified and isolated. Those areas with low anomaly and high depths are sufficient for hydrocarbon accumulation.

Keywords: Tilt angle derivative, satellite gravity data, edges, depth.

INTRODUCTION

The Historical Background of the Chad basin has shown that there is a possibility of finding many resources and other important information which will be of benefit to humanity. This idea drew the attention of many researchers to the basin and many important mineral resources are continuously explored on the basin. Nigeria being one of the countries containing some segments of the basin will continue to benefit from Mineral and energy resources explored from within. The Federal Government has recently placed concern to re-examine the basin. This serves as a call for re-evaluation of the prospect of different areas of the basin (Ola *et al.*, 2017).

Previous workers, notably, Babatunde *et al.,* (2020), Sulaiman *et al.*, (2021), Kehinde *et al.*,(2018), Anakwuba and Chinwuko (2015), Adekoya *et al.*,(2015) evaluated the potential in some parts of the basin suggesting that the basin contain sufficient hydrocarbon generation elements. Most of them have taken the whole Nigerian Chad segment or portions other than the Hadejia segment. As it is known that a survey starts from whole to part, we are now taking a particular portion. Little or no research has taken Hadejia segment particularly for the purpose of petroleum and mineral exploration. Most of the geophysical works around the area are for ground water and related purposes.

Also few of those researches used gravity method and recent improvements in observation, processing and data analysis due to technological advancement have made gravity method more efficient and more sensitive and more applicable to a wider range of problems (Justia *et al.*,2018). This made the present research adopted gravity method. Gravity method is a potential field method that uses the difference of acceleration which brings about change in density to infer about subsurface structures.

Tilt angle filter is a mathematical method used to compute the gravity data in this research. It is an interpretation method usually used to determine the source border locations from potential field data (El-Tokhey *et al*, 2015). Moreover, the tilt angle is applied for the estimation of the depth of source of anomaly. In this paper, the tilt angle technique obtained from the first vertical and horizontal gradients of gravity anomaly from a semi-infinite vertical cylindrical source is applied to the Bouguer data of the study area. In this method the depth estimates are proportional to their separations from the cross section center of the anomaly cause on the surface and the computed tilt angles (Eshaghzadeh, 2017). The tilt angle technique has been used as the basis for a variety of methods for edge enhancement of potential field anomalies (Cooper, 2013; Ferreira *et al*, 2013).

MATERIALS AND METHODS

Materials used for this research include

- Oasis Montaj software
- Surfer software
- Satellite gravity data

The data used is the satellite gravity data of part of the Nigerian Chad basin which lie between latitude 11^0 -13^0E and longitude 8^0 - 14^0N obtained from Bureau Gravimetrique International (BGI) on 11th March 2020.

Determination of the of the earth's field of gravity from space involves measurement of the satellite height above sea level by radar altimetry. Satellites such as Skylab, GEOS3, SEASAT, Geosat, ERS1,and ERS2 have been used for gravity data acquisition (Foulger and Peirce, 2010). SEASAT is the one used by BGI to obtain data. It was launched into a circular orbit with an altitude of 800km in 1978. It circles the earth 14times daily and covers 95% of the earth's surface every 36 hours. The satellite continually transmit a radar signal which bounced off the sea surface. The two way travel time was measured and the used to find height and then the value of acceleration due to gravity.

Description and Geology of the Study Area

The study area lies on the north eastern part of Jigawa State and north western Yobe state on latitude 12^0 13'N to 13^0 60'N and longitude 9^0 22'E to $11^0$00E. Rocks and younger sediments of Chad formation lie beneath the area. The climate of the area is semi-arid with short wet season from June to September and long dry season for rest of the year. It has average annual temperature of 27.2^oC and 600mm to 762mm total annual rainfall. The regional vegetation falls within the Sudan Savannah type with few scattered trees and extensive open grassland (Ekanem *et al.,* 2016). Nigeria occupies approximately 10% of Chad Basin in the middle of latitude 11^oN and $13^o45'38''$N and longitudes $8^o21'49''$ and 14^o $40'22''$E (kwaya *et al.,* 2018). 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). Fig. 1 is a Nigerian map showing the study area in the Nigerian sector of Chad basin.

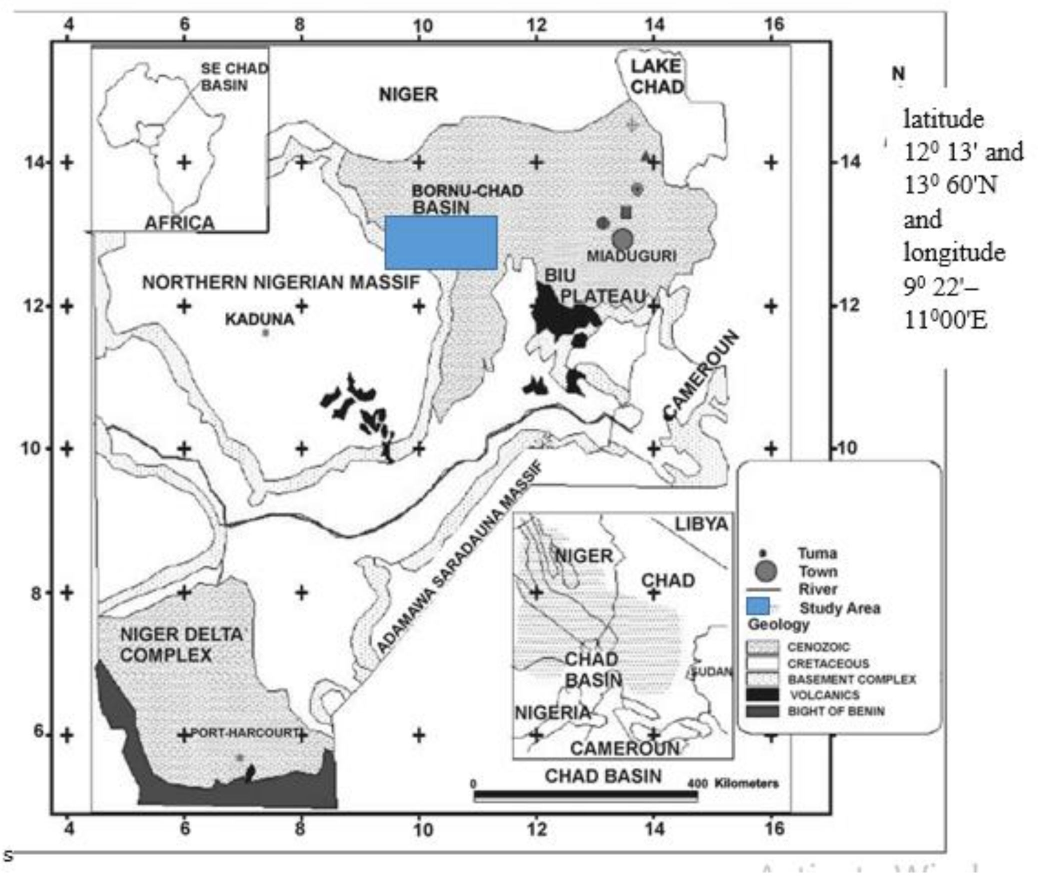

Fig. 1: Nigerian map showing Chad basin area.

Tilt Angle Method

Tilt angle of gravity anomalies is the ratio of the vertical derivative of anomalies to their horizontal derivative (Miller and Singh, 1994).

The total horizontal component (HGM) is defined as follows:

$$HGM = \sqrt{\left(\frac{\partial g}{\partial x}\right)^2 + \left(\frac{\partial g}{\partial y}\right)^2} \qquad (1)$$

Where g= gravity anomaly, x= longitude, y= latitude

The vertical gradient of the gravity values $\partial g/\partial z$ is the ratio of the difference in the magnitude of the gravity vector at a point on two different vertical points to the distance between them. It is based on the idea that the gravitational field vector g can be derived from the gradient of gravitational potential U.

$$g = -\nabla U \qquad (2)$$

Which obeys Laplace equation

$$\nabla^2 U = \nabla . \nabla U = - \left(\frac{\partial g}{\partial x} + \frac{\partial g}{\partial y} + \frac{\partial g}{\partial z}\right) = 0 \qquad (3)$$

(Ibe and Iduma, 2018)

and thus $$\frac{\partial g}{\partial z} = -\left(\frac{\partial g}{\partial x} + \frac{\partial g}{\partial y}\right) \qquad (4)$$

The tilt angle filter is defined as

$$\theta = arctan \frac{\frac{\partial g}{\partial z}}{\sqrt{\left(\frac{\partial g}{\partial x}\right)^2 + \left(\frac{\partial g}{\partial y}\right)^2}}, \qquad (5)$$

Where θ is the tilt angle and g is gravity anomaly.

The gravity anomaly due to semi-infinite vertical cylinder is given as

$$g = \frac{\pi G p R^2}{(x^2+z^2)^{1/2}} \qquad (6)$$

G is the universal gravitational constant, p is density, R is radius, x is position coordinate and z is the depth.

The horizontal derivative $$\frac{\partial g}{\partial x} = \frac{-\pi G p R^2 x}{(x^2 2+z^2)^{3/2}} \qquad (7)$$

And the vertical derivative $$\frac{\partial g}{\partial z} = \frac{-\pi G p R^2 z}{(x^2+z^2)^{3/2}} \qquad (8)$$

Substituting 7 and 8 in 5 gives

$$\theta = \tan^{-1}\left(\frac{z}{x}\right) \qquad (9)$$

and $$z = x\tan\theta \qquad (10)$$

Where x=Δx which is the distance of gravity points from origin. (Eshaghzadeh, 2017)

RESULTS AND DISCUSSION

The data had undergone Bouguer correction already. It was then converted from the excel file format to dat file format. Its grid was obtained using the surfer software and subsequently the contour map was plotted using the same software. Fig. 2 shows the contour map of the study area which reflects the density changes.

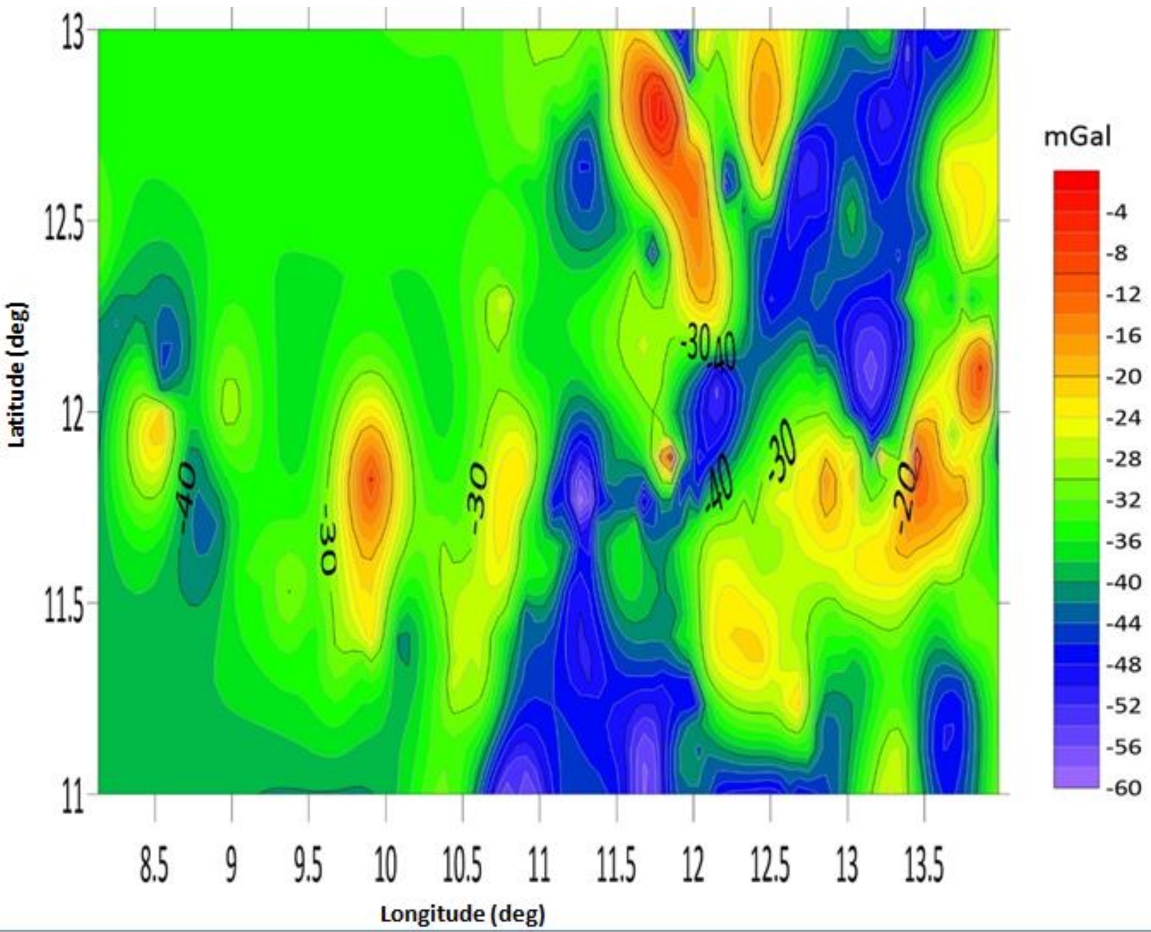

Fig 2: The Bouguer gravity map

The Bouguer map in fig 2 shows areas of high density and areas of low density. In general, high gravity anomaly regions may perhaps be due to the existence of subsurface denser rocks or due to shallower or near surface uplifted blocks of basement rocks. Low gravity anomalies are detected in the dominant part of the map with its minimum value appearing in the south-eastern and north-eastern part of the map. Low gravity anomalies are suggesting that there is existence of thick sedimentary sections.

The first derivatives obtained in excel software were used to obtain the tilt angle derivative in the same software. The new data was then fed into surfer where the tilt angle grid was obtained and the gridded data was used to obtain the tilt angle map as shown in fig 3.

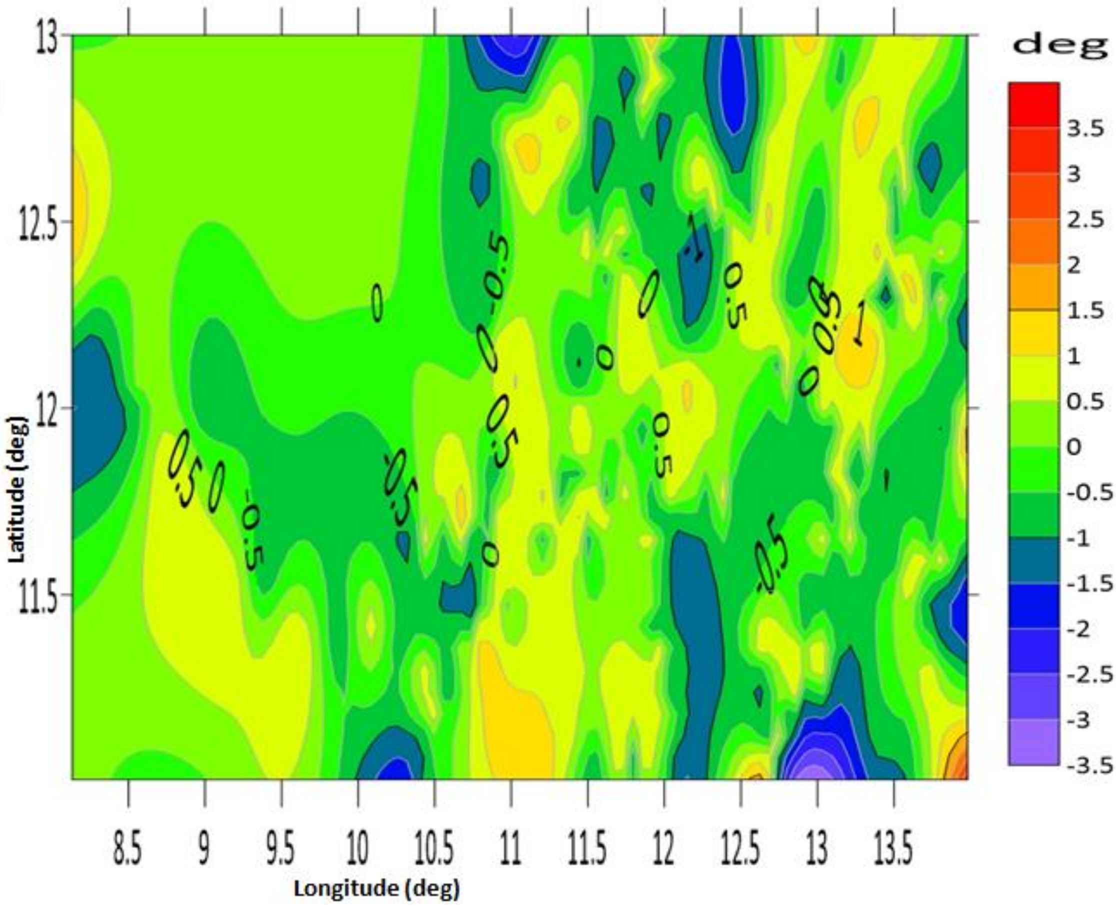

Fig 3: The tilt angle map of the study area.

The tilt angle map in fig 3 shows the angle between portions that have different values of density. It shows the tilt derivative data which noticeably show the orientation structure of fault that correlates with the geological structure. The angle ranges between -3.5 degrees to 3.5 degrees with edges/boundaries between the two formations considered at angle zero. Negative values are moving toward the source of sediments while negative values are moving away from the source. The sediments are concentrated around areas with blue and purple colours because they have higher negative values. Interestingly, those areas coincided with those revealed by Bouguer map in figure 2. The advantage of the tilt derivative method is well suitable to all source condition of the subsurface; shallow and deep sources (Yanis *et al*, 2019). The tilt derivative map is a map of the geology structure which has a regional characteristic and shows minor faults which has the residual anomaly.

The tilt angle data was used to obtain the depth using the relation in equation 13 in excel software. It was then gridded using surfer softwre and subsequently the tilt angle map was plotted to reflect the depth to source of anomaly.

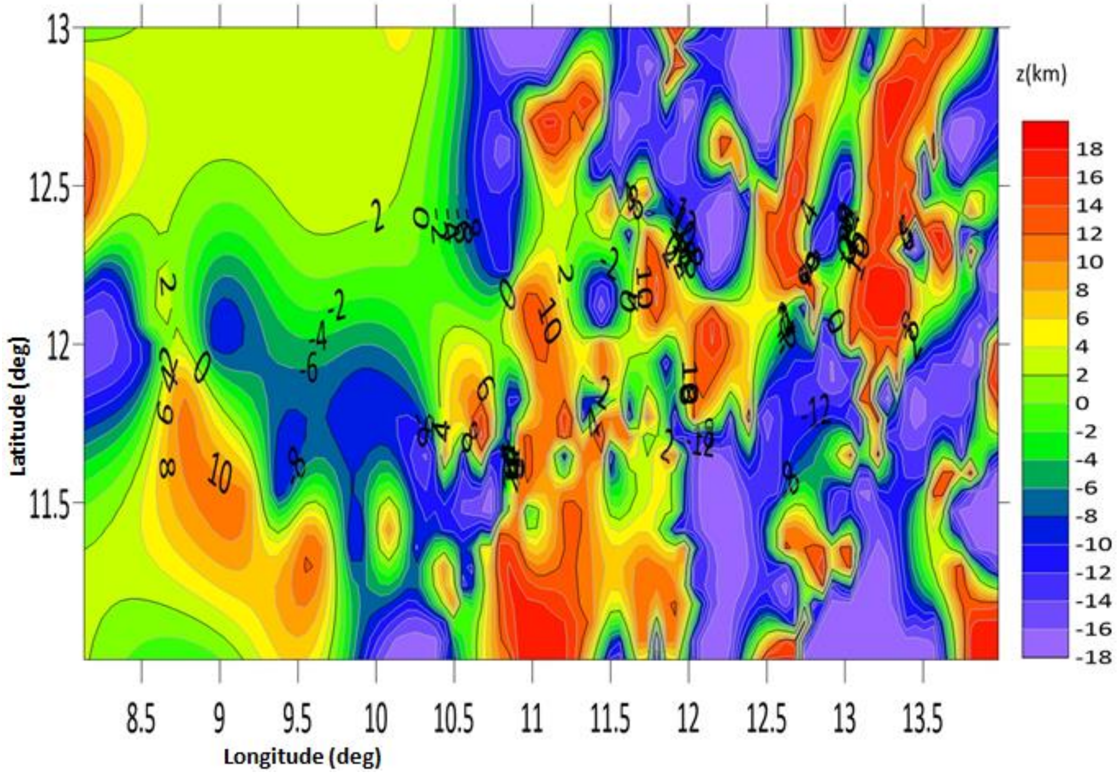

Figure 4: Depth to basement of study area derived from the tilt angle

Fig 4 shows the depth to the basement of the anomalies. It has shown that the area has a depth that ranges between 2km to 18km.The negative sign attached to the values on the legend also signifies depth (Mbah *et al*, 2017). The positive and negative signs of depth are as a result of positive and negative angles observed at the tilt angles. The value z is the depth to the top. It is impossible to estimate the minimum depth to the top of a body, but fortunately it is the maximum depth that is important for making drilling decisions. Those areas identified as sedimentary in fig 3 and observed to have depth more than 3km depth in fig 4 are areas with higher expectation of hydrocarbon accumulation.

The values are not in conflict with depths obtained by other researches like Babatunde *et al.*, (2020) that estimated the sedimentary using Spectral analysis and source parameter imaging (SPI) to find the depth estimate of 1.2–8.3 km. Sulaiman *et al.*, (2021) estimated depths from the forward and inverse modeling methods for profiles 1-7 between 2.7km to 6.9km within the basin. Kehinde *et al*.,(2018) used spectral analysis to find depth of magnetic sources in the range of 1.34 to 3.42 km. Adewumi *et al.*, (2017) used spectral analysis to estimate the sedimentary thickness that ranges between 0.29 km and 3.35 km. Anakwuba and Chinwuko (2015), utilized one dimensional spectral analysis to aeromagnetic data to find shallow sources to have a mean value of 2.21 km to 14.07 km and depths to the centroid and magnetic bodies (sedimentary thicknesses) range from 11.55 to 18.32 km and 1.65 to 5.12 km respectively.

The coincidence of the values with findings of other researchers especially Anakwuba and Chinwuko (2015) serves as a tool to validate the present research.

CONCLUSION

Tilt angle method was applied on satellite data of the study area. The edges or boundaries of sources of anomaly were determined as well as the depth to the basement. The edges of geologically anomalous density distributions were defined and geologic units are identified The tilt angle map shows angle between -3.5 degrees to 3.5 degrees. The zero values indicated boundaries between sedimentary basin and basement complex. Based on the data of sediment thickness using tilt angle, it was found that the study area has a depth that ranges between 2km to 18km. Sedimentary thicknesses determined and faults delineated are regularly used successfully to select a target area in exploration of hydrocarbon because of their influence in heat generation for source rock maturation and hydrocarbon migration. Records about subsurface geometry and depth are very vital for a correct description of the type of formation.

The airborne geophysical data of the study area demonstrates significant basement structures connected with deposit underlying the cover sediments of the study area. The values obtained has revealed the potential of the area to accumulate minerals especially hydrocarbon. The study contributed to the ongoing efforts of delineating hydrocarbon traps within the basin.

ACKNOWLEDGEMENT
I acknowledge the effort of the 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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