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DEPTH TO BASEMENT ESTIMATION AND BASEMENT TOPOGRAPHIC MAPPING FROM AEROMAGNETIC DATA ACQUIRED OVER THE CENTRAL PART OF THE BORNO BASIN, NORTHEASTERN NIGERIA; IMPLICATIONS FOR PETROLEUM EXPLORATION

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ABSTRACT

A reconnaissance for petroleum exploration was conducted in the central part of the Nigerian sector of the Chad Basin (Borno Basin) using High Resolution Aeromagnetic Data (HRAM) obtained from the Nigerian Geological Survey Agency (NGSA). The study was aimed at identifying high-prospect areas by estimating sedimentary thickness and mapping basement geometry. Upward continuation eliminated shallow magnetic sources, making it easier to focus on deeper regional geologic structures thought to have originated from the basement. To make the anomalies easier to interpret, the reduction to equator processing approach was employed to concentrate them on the associated geologic causes. At various solution positions, the depth to basement rocks was calculated using a new 3D Located Euler Deconvolution depth weighting method. The rocks in the study area have residual magnetic intensities ranging from -275 to 190 nT. The basement topography exhibits undulations and thicknesses varying from around 100 m to over 3 km, as indicated by the results of the Euler Deconvolution and the basement topographic map. Four major sub-basins, situated in the southern and northeastern parts of the study area, with thicknesses ranging from > 2.5 to up to 3 km, with the largest sub-basin, situated in the southern portion of the study area, having the highest thickness, up to 3.4 km in certain areas. These sub-basins are thick enough to generate geothermal gradient for organic matter maturation where the right source rock exist hence recommendable for further geophysical investigation using reflection seismic and other petrophysical studies.

Keywords: Borno Basin, Depth to basement, Petroleum prospect, Euler Deconvolution

INTRODUCTION

The Chad Basin is a giant intracontinental sedimentary basin (Burke, 1976) associated with the West Central African Rift System (Genic, 1993), spanning five nations, including Cameroon, Central African Republic, Chad, Niger, and Nigeria (Obaje, 2009). The Nigerian portion of the basin, known as the Borno Basin is one of the major sedimentary basins in Nigeria, situated at the eastern part where it is bounded by the Benue Trough and Adamawa highland to the south and central Nigeria basement complex to the west. Despite various exploration campaigns conducted in the Borno Basin, no success has been recorded, unlike in the neighboring basins with shared tectonic and evolutionary history to the Borno Basin such as the Eastern Niger Rift Basin (Ahmed, 2020), Bongor Basin of Chad Republic (Dou, 2020) and Muglad Basin in Sudan (Xiao, 2019) where petroleum production is ongoing. However, previous studies especially on petroleum geochemistry suggest high potential for both oil and gas generation in the Borno Basin (Olugbemiro et al., 1997; Obaje, 2004).

The Nigerian portion of the Chad Basin has witnessed the execution of a number of geophysical investigations, notably those involving the interpretation of aerial magnetic data for petroleum development. These investigations, which mostly used source parameter imaging (SPI) depth estimation methods and spectral analysis, include those of Lawal et al. (2015), Akiishi et al. (2018), Arogundade et al. (2020), and Chinwuko et al. (2012). In order to delineate high prospect areas for potential petroleum generation and preservation, this study used high resolution airborne magnetic data acquired over the central part of the Borno Basin for depth to basement estimation and basement topographic mapping using 3D Located Euler Deconvolution technique. The study area is situated between latitudes 11^0 30' N and 13^0 15' N and longitudes 10^0 30' E to 11^0 30' E. The study's specific goals are to determine the thickness of the sedimentary layer by measuring the depth to basement using the 3D localized Euler Deconvolution approach and to compare the magnetic signals with the geology of the study area. Furthermore, the topography of the basement located beneath the research area will be ascertained.

The Nigerian sector of the Chad Basin, locally known as the Borno Basin is part of a broader Chad Basin which extended into five countries, namely: Cameroon, Central African Republic, Chad, Niger, and Nigeria, lies between the West African Craton and Congo Craton is a Phanerozoic sedimentary basin which was formed during the plate divergence that opened the South Atlantic Ocean (Obaje, 2009). The study area covers the central part of the basin (Fig. 1), which like other parts of the basin, it is blanketed by Tertiary to recent sediments.

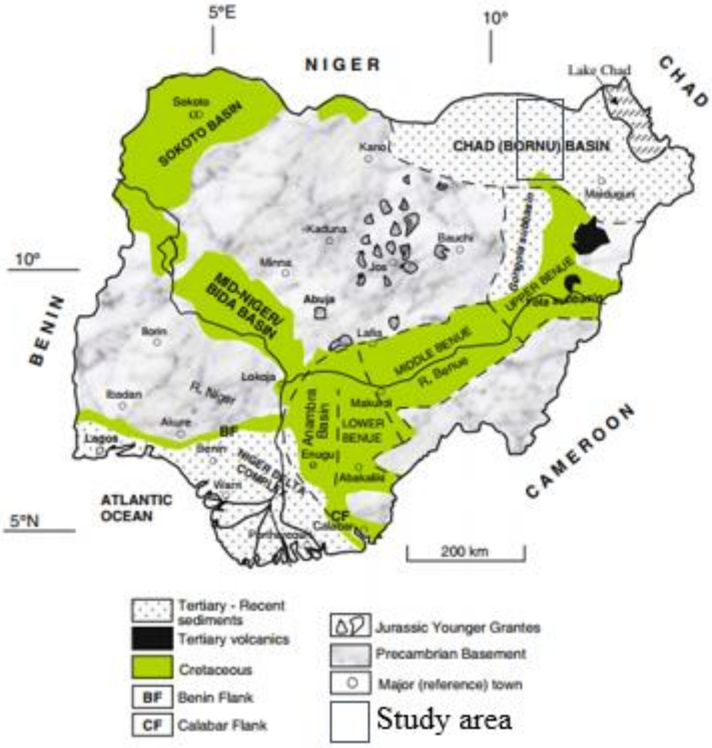


Figure 1: Geological map of Nigeria showing the location of the study area (modified from Obaje, 2009)

In the Nigerian sector of the Chad Basin, the geology is primarily inferred from boreholes, well logs, and the Benue Trough; a few early Cretaceous older units are examined in the Niger Republic portion of the basin due to a lack of outcrops, according to authors like Avbovbo et al., 1986; Obaje, 2009; and Olabode et al., 2015. The stratigraphic units in the Borno Basin of Nigeria are the Bima Formation, Gongila Formation, Fika Shale, Kerri-Kerri Formation, and Chad Formation. Nevertheless, other writers have identified six stratigraphic units in the region, including the Gombe Formation (Avbovbo et al. 1986; Obaje, 2009).

MATERIALS AND METHODS

The aeromagnetic data collected from the study area is part of the high-resolution aerial geophysical surveys conducted in Nigeria, which also include electromagnetic, radiometric, and magnetic surveys. Data collection was done by Fugro airborne surveys on behalf of the Nigerian Geological Survey Agency (NGSA). Data were gathered at an 80 m sensor mean terrain clearance with a 500 m flight line spacing and 5000 m tie line spacing, respectively, as well as a NE-SW and NW-SE flight line trend, using a three x Scintrex CS3 Cesium Vapour Magnetometer (NGSA, 2020). The acquired pre-processed data was subjected to various processing techniques, which were interpreted to give meaningful geologic outputs. These data processing and interpretation sequences include upward continuation, reduction to equator, analytic signal, vertical and horizontal derivatives, and the three-dimensionally located Euler Deconvolution depth weighting technique. The process of upward continuation attenuated lower wavelength anormalies by transforming magnetic data acquired at a specific elevation to a plane higher than the plane of measurements (Biyiha-Kelaba et al, 2013) as shown in equation 1. Because it lessens or completely removes the impact of noise and shallow sources in grids, upward continuation is considered a clean filter, obviating the need for additional filters or correction techniques.

$$L(K) = e^{-2\pi hk} \qquad (1)$$

Where:
h is the distance to upward continue and k is the wavenumber (cycle/ground unit)

In light of the low latitude location of the study area, the data was further reduced to the equator (equation 2) in order to concentrate the anomalies over the relevant geologic sources into a form that has a straightforward relationship with the study area's geology. This will assist in preventing interpretation ambiguity brought on by instability resulting from low latitude and instability occurring when the total magnetization field or the inducing field's inclination is near zero; as a result, the absolute value is less than 5° and leads to an inaccurate estimation of the magnetization direction (Gerovska et al., 2009).

$$L(\theta) = \frac{[\sin(I) - i\cos(I).\cos(D-\theta)]^2 \times (-\cos^2(D-\theta)}{[\sin^2(Ia) + \cos^2(Ia).\cos^2(D-\theta)] \times [\sin^2(I) + \cos^2(I).\cos^2(D-\theta)]},$$

$$\text{if } (|Ia| < |I|), Ia = I \qquad (2)$$

where D is the geomagnetic declination and I and Ia are the geomagnetic inclination and inclination for amplitude correction, respectively.

Where remanence magnetization complicates interpretation or at low magnetic latitudes, the analytical signal proposed by Nabighian (1972 and 1984) is well suited for identifying the borders of magnetic source bodies. The analytical signal is independent of the magnetic field's inclination, in contrast to the traditional reduction to the pole. In order to get the anomalies to the top of their causative bodies, this overcomes the challenges that are frequently encountered in the traditional reduction to pole approach. The analytic signal can be quantitatively represented by the square root of the total of the data derivatives in the x, y, and z directions, as shown in equation 3.

$$AS = \frac{\partial M}{\partial x} + \frac{\partial M}{\partial y} + \frac{\partial M}{\partial z} \quad (3)$$

where the horizontal derivatives in the x and y directions are, respectively, $\frac{\partial M}{\partial x}$ and $\frac{\partial M}{\partial y}$ while the vertical derivative is $\frac{\partial M}{\partial z}$

Equation 4, a novel approach to 3D-located Euler deconvolution depth weighting, was adopted. Its benefits include its effectiveness even in the absence of prior knowledge about the direction of the source magnetization and its invariance to remanent magnetization (Ravat, 1996). Thompson (1982) was the one who first proposed the technique, while Reid et al. (1990) later extended it. Keating (1998), Mushayandebvu et al. (2004), and numerous others have since modified and enhanced it. Its widespread use and ease of implementation make it the go-to tool for rapid first interpretations, which contributes to its appeal.

$$\frac{(x-x_0)dT}{dx} + \frac{(y-y_0)dT}{dy} + \frac{(z-z_0)dT}{dz} = N(B - T) \quad (4)$$

Finding the grid peak positions and the horizontal (dx and dy) and vertical (dz) derivatives needed for the computation of analytical signals was the initial step in the process. The 2D and 3D basement topography underpinning the research region was created by constraining and plotting the solutions of the three-dimensional (3D) Located Euler Deconvolution.

RESULTS AND DISCUSSION

Residual magnetic intensity map

The residual magnetic intensity map of the study area, as presented in Fig. 2, shows the range of magnetic intensity values of the rock units underlying the study area. The values range from approximately -275 to 190 nT. High magnetic intensity values dominate mostly the central part of the study area, though there are some patches of low magnetic intensity regions. Low magnetic intensity regions, on the other hand, dominate the northern and southern parts of the study area. This wide range of variation in magnetic intensity indicate the existence of both basement and sedimentary rocks in the study area or variation in sedimentary thicknesses or depth to basement from place to place (Osinowo and Abdulmumin, 2019).

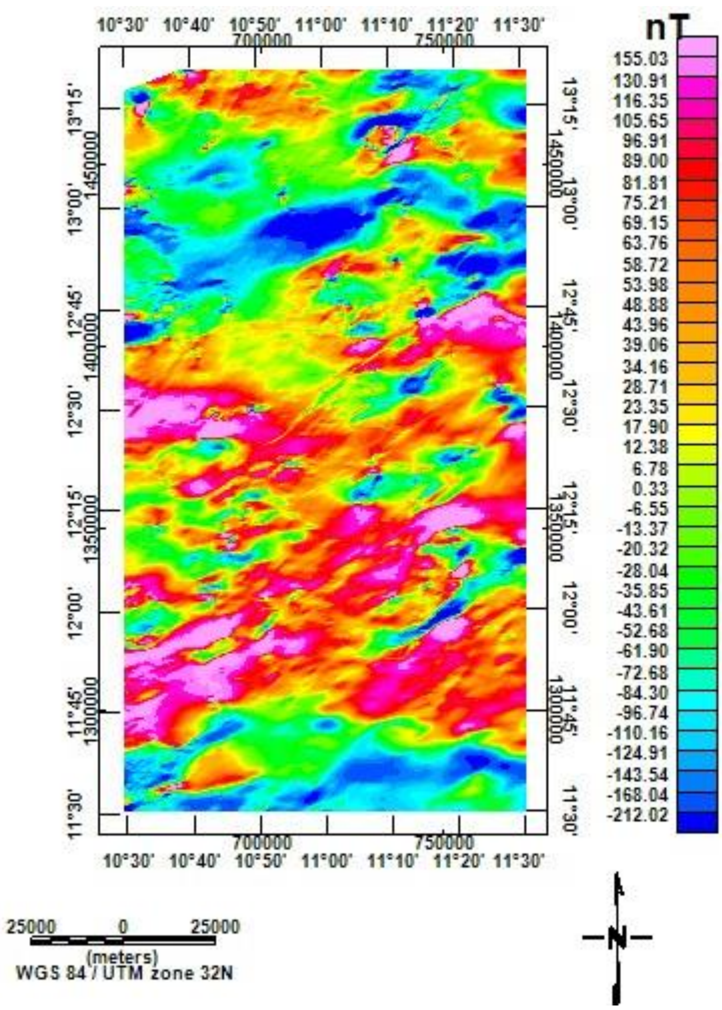


Figure 2: Residual magnetic intensity map of the study area

Reduced to equator map

After applying a reduced to equator transformation filter, the study area's map is displayed in Fig. 3. The magnetic intensity values in the study area range from -275 to 170 nT, with high-intensity areas dominating in the center and low-intensity areas dominating in the north and south. A partial transformation of anomalies produced by the limits of the Reduced to Equator transformation method is suggested by the map's minimal deviation from the region's residual magnetic intensity map (Fig. 2), particularly in low-latitude locations with remanent magnetization.

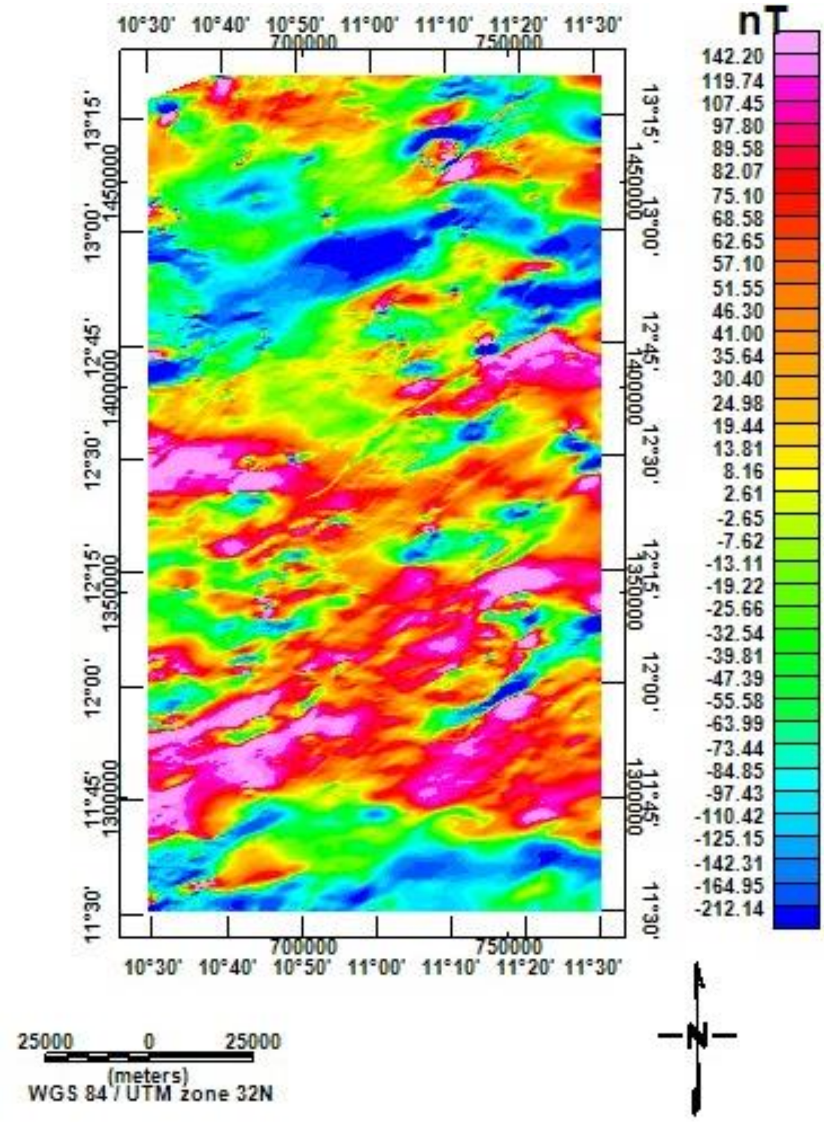


Figure 3: Reduced to equator map of the study area

Analytic signal map

The analytical signal map of the Nigerian sector of the Chad Basin's center region is shown in Fig. 4. The values of the analytical signal range from 0.014 to 0.209. Based on the analytic signal values, the study area may be split into two zones: the high signal areas are associated with shallow basement rock, while the low signal areas are associated with thicker sedimentary sequences. The study area's northern, northwest, southeastern, and southwest regions are primarily home to high-signal zones, which are dotted with low-signal areas. Conversely, the E, NE, and western regions of the research area are dominated by the low-signal zones.

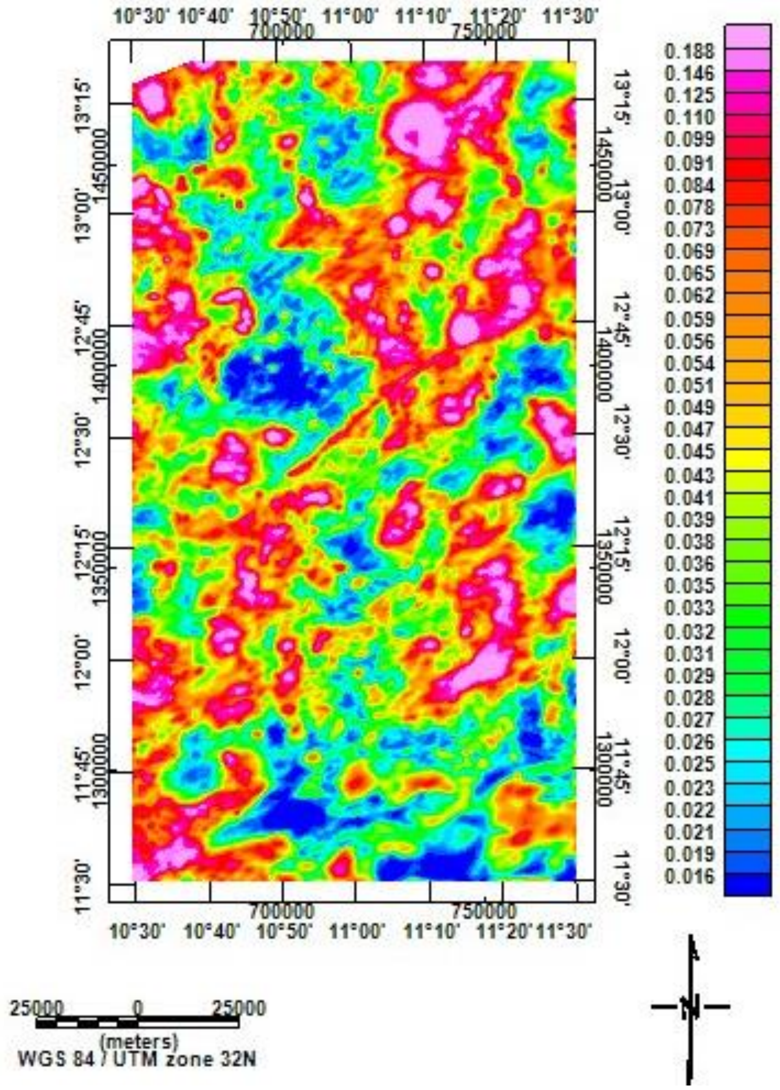


Figure 4: Analytic signal map of the study area

Depth to basement map

The depth to basement map generated from 3D-located Euler Deconvolution is presented in Fig. 5. The map shows variations in depth to basement values across the study area, ranging between -3400 m and 100 m below and above the Minna datum, respectively. Higher depth to basement (elevation) values indicates areas where depth to basement is shallow, while lower elevation values correspond to areas underlain by thicker sedimentary sequences (Osinowo and Abdulmumin, 2019). The map shows that thicker sedimentary successions dominate mostly the southern, western, and eastern parts of the study area, with significant patches in the northern and northwestern parts of the study area. These thicker portions are where high geothermal gradient is expected for organic matter maturity and possible accumulation in the presence of appropriate lithologies and structures. The depth estimates discovered in this work are consistent with what other authors, including Nur et al. (2011), Anakwuba et al. (2011), Chukwunonso et al. (2012), Nwobodo et al. (2018), and Usman and Jibril (2020), have recorded in the same and nearby basins.

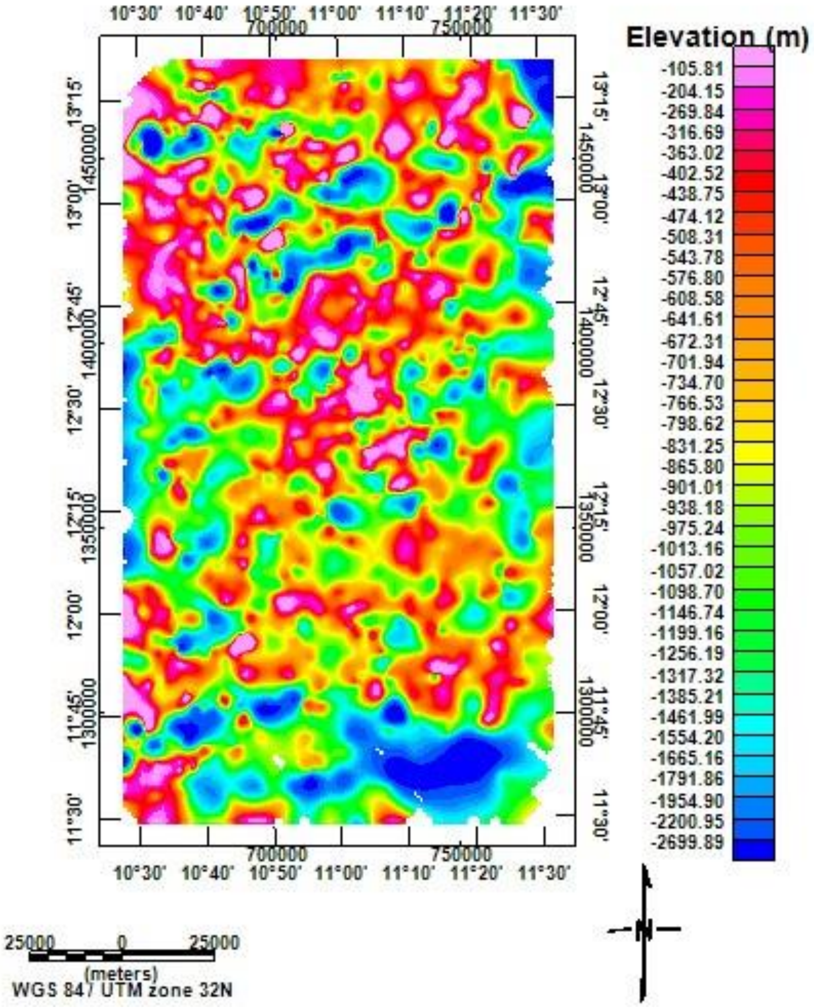
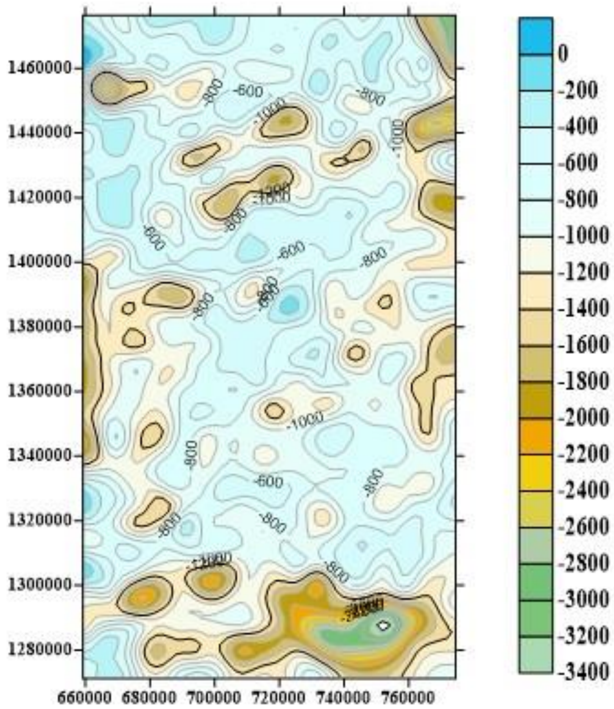


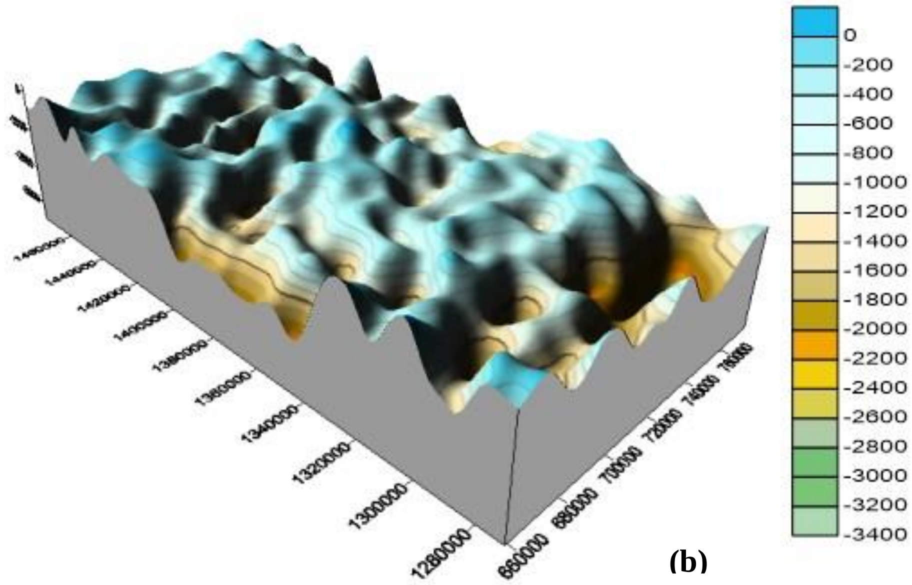
Figure 5: Depth to basement map of the study area

Basement topography

Figs. 6a and 6b, respectively, show the 2D and 3D maps that show the topography beneath the research region. According to the maps, the research area's topography is undulating, with a large number of sub-basins spaced throughout it that are divided by highs of igneous origin. Within the sub-basins, the most extensive and thickest is found in the southern portion of the research region. Its center reaches a thickness of up to 3.4 km, and its length and width measure 25 and 60 km, respectively. Another sub-basin of similar thickness is located at the extreme northeastern part of the study area, with a thickness of almost 3 km but with a lesser extent compared to the giant sub-basin at the southern part of the study area. These kinds of settings are capable of generating and preserving hydrocarbons if the right conditions are present. With a thickness of over two kilometers, three additional sub-basins can be explored further. Two of these sub-basins are situated in the study area's southern section, west of the massive sub-basin, and the other one is in the northeastern section, directly beneath the sub-basin at the far northeast of the study area.



(a)



(b)

Figure 6: a – 2D basement topographic map of the study area
b – 3D basement topographic map of the study area

CONCLUSION

The study has shown how well the high-resolution aerial magnetic data worked for conducting the reconnaissance study needed for oil prospecting in the central Nigerian section of the Chad Basin. Five significant sub-basins have been found and delimited by the study; two of these are located in the northeastern portion of the study area and three of them are located in the southern portion. These sub-basins have the potential to contain substantial petroleum resources that may have been produced under the correct circumstances, thus they may be investigated in detail using cutting-edge geophysical methods.

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