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Structural-depth analysis of the Yola Arm of the Upper Benue Trough of Nigeria using high resolution aeromagnetic data

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A B S T R A C T

The Yola Arm is the east-west trending part of the Upper Benue Trough made up of Cretaceous sediments that are Albian to Maastrichtian in age. This work involves interpreting satellite imagery and aeromagnetic data to map out structures within the basin and estimate the depth to the magnetic basement which could be an aid to further exploratory work in the basin. The SPOT 5 imagery covering the basin was processed and interpreted and lineaments extracted from it. The digital elevation model (DEM) of the area was also used to extract the drainage pattern of the area and as an aid in mapping the lineaments that are visible on the surface. The geomagnetic field of the earth was removed from the aeromagnetic data using the IGRF-12 model. The vertical derivative (VDR) enhanced the high frequency and short wavelength components of the data which could be volcanics. The source parameter imaging (SPI) technique which works well at all magnetic latitudes and the spectral analysis were applied to the data to estimate the sediment thickness within the basin. A low pass filter with a cut-off wavelength of 1000 m was applied to the data to remove the high frequency short wavelength component of the data after which the tilt derivative (TDR) was computed to enhance anomalies that may be faults on the underlying basement. The lineaments from the SPOT 5 data show a predominant NNE-SSW, NE-SW followed by the NNW-SSE with a few N-S and E-W trends and the TDR of the aeromagnetic data show a predominantly NE-SW trend which is the predominant trend in the Benue Trough while a few strike in the N-S,NW-SE, and WNW-ESE direction. This suggests that the basin was subjected to several stress regimes. Differential uplift of the basement fault blocks may have given rise to drape folds observed in the overlying sediments. The depths to the magnetic basement range from about 1 km to about 4.3 km with the deepest part in the eastern part of the Basin. The depth analysis indicates that the Cretaceous sediments are thick enough to generate hydrocarbons.

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1. Introduction

The Upper Benue Trough (Fig. 1) of Nigeria is comprised of three basins: the east–west trending Yola Basin (Yola Arm), the north-south trending Gongola Basin (Gongola Arm) and the northeast-southwest trending Lau Basin (Main Arm). The Benue Trough is itself a product of the West and Central African Rift System in 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 super continent called Gondwanaland 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 (Burke et al., 1970). This present work is an attempt to understand the structural framework and the geometry of the basin which can be an aid to further exploratory efforts in the basin. It involves processing and interpreting high resolution magnetic data collected at 400 m flight line spacing by Fugro Airborne surveys which is an improvement on past interpretations that were done with the old data that was collected in 1972 at 2 km flight line spacing. This improvement in data quality will give a better understanding of the basin and also give more accurate depth to basement values. This study is aimed at showing the effectiveness of integrating remote sensing, magnetic and other ancillary data within a GIS for geological/structural studies. When interpreting aeromagnetic data, it is necessary to compare structures or

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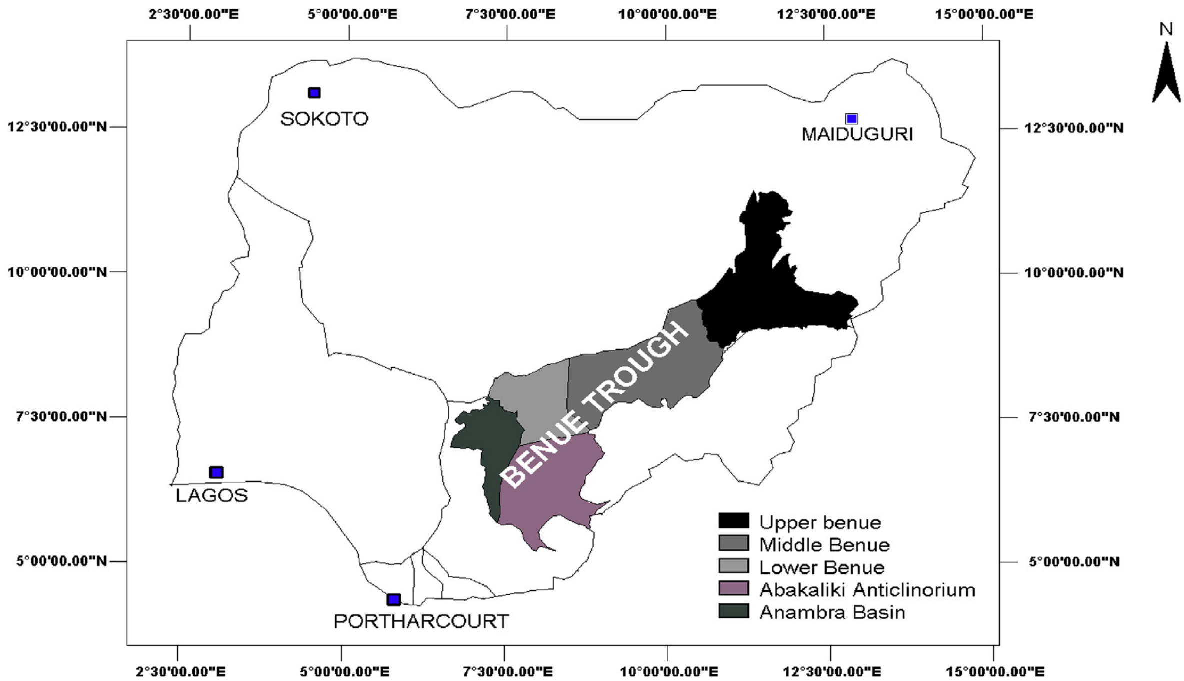

Fig. 1. Map of Nigeria showing the major subdivisions of the Benue Trough (after Ologun et al., 2008).

magnetic anomalies delineated from the derivatives with the surface features as can be seen from aerial photographs or satellite images. Remote sensing has become a widely accepted research tool by geologists the world over. It gives the overview required to construct regional unit maps, useful for small scale analyses, and planning field traverses to sample and verify various units for detailed mapping. It is also used to understand the spatial distribution and surface relationships between rock units. For this study SPOT 5 image with a spatial resolution of 5 m was used. Satellite imagery can give us a picture of the surface where outcrops and features such as dykes can be observed. Also rock units and geological structures often show a strong correlation with relief and can be mapped with a detailed topographic analysis. Digital Elevation Models (DEM) are used for such analysis to derive topographic attributes such as elevation, slope, aspect, shaded relief, drainage network, etc with the aid of a Geographic Information System (GIS).

Magnetic data interpretation can be used to establish the relationship between basement tectonics and the overlying structures within the sediments. The 1st vertical derivative is a vertical gradient method that uses a Fast Fourier Transform (FFT) to enhance the high frequency component of a magnetic field made up of intrusives and volcanics while suppressing the low frequency content which is due to the regional field. The tilt-derivative (TDR) is a powerful method because of its peculiar characteristics and it was used to enhance the basement faults. It attempts to equalize the amplitude output of TM anomalies across a grid. All other derivatives have an amplitude response that is closely linked to the amplitude of the TMI anomaly but the TDR is independent of amplitude of the anomaly and are instead controlled by the reciprocal of the depths of the magnetic sources. It is also a good signal discriminator in the presence of noise. The Source Parameter Imaging (SPI) technique so called because all the parameters that make up the source which include depth, dip and susceptibility contrast are computed from the complex analytical signal was used for this study because the technique assumes only induced magnetization and works well at all magnetic latitudes which makes it a good choice for the Yola basin that is at low magnetic latitude. The spectral analysis method was also used for this study in order to compare with the estimates from the SPI because it has the advantage of being able to filter out noise from data without losing information during the process.

In the Northern Gulf of Mexico, Alexander, (1999) integrated magnetic, gravity, seismic and refraction data to map out the geometry of the basement and was able to map out grabens and the horst structures within the basin and also identified the primary faults within the basement and the secondary faults in the overlying sediments. In the past, interpretations of magnetic data was done using data with a 2 km flight line spacing that can only resolve structures of >4 km resolution but recent data acquired can resolve structures as low as 400 m which will give a better interpretation of the basin. Understanding the deformation that occurred within the basement can help understand the resultant deformation and stratigraphy of the basin. This present work attempts to interpret aeromagnetic data with the aid of ancillary data such as satellite imagery and digital elevation model (DEM) to map out the basement geometry and structures within the basin which can be an aid for further detailed exploratory work.

1.1. Geological setting

The area of study forms part of the Upper Benue Trough of Nigeria (Fig. 1) which is a product of the West and Central African Rift System where it opened as a broad strike-slip fault system (Binks and Fairhead, 1992).

The area falls within latitude 9° 03′ N to 10° 00′ N and longitude 11° 30′ E to 13° 00′ E. It covers an area of about 12,000 km^2. The geology consists of crystalline basement, Cretaceous sediments and volcanics (Fig. 2).

A horst and graben structure which resulted in variation in sedimentary thickness of between 2 and 3 km was deduced from interpretation of aeromagnetic data of the lower Benue (2 km flight line spacing). It also revealed a major lineament trend of NE-SW (Obi et al., 2008). Okereke et al. (2012) observed a major NE-SW

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