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Application of scaling geology in magnetic basement mapping around the Middle Benue Trough in Northcentral Nigeria

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Highlights

- •
  Scaling spectral method was applied on high resolution aeromagnetic data
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  We estimated a depth range of 1.8–6.3 km to the basement beneath the Cretaceous sediments of the trough and a corresponding scaling exponent ranging from 0 to 2.
- •

There were some correlations with the geology of the area, particularly around the crystalline basement complex in the northern portion. However, the source distributions are less correlated, uneven, and not always consistent with the geology of the area around the central portion which is attributed to intrusions.

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  This method tends to be more reliable as the degree of correlation of the magnetic sources were taken into account for the first time in most parts of the study area.
- •
  As a result, this present work will provide more useful insights into groundwater, mineral, and hydrocarbon explorations in the area.

Abstract

Using the scaling spectral method applied on high resolution aeromagnetic data, we mapped the magnetic basement and estimated the scaling exponents across various lithologies within the Middle Benue Trough of Northcentral Nigeria. We estimated a depth range of 1.8–6.3 km, with an average of 3.7 km to the basement beneath the Cretaceous sediments of the trough. Shallow basement depths of <3 km are mostly found on the trough's northern and southeastern margins. These are uplifted Precambrian Basement Complex regions made up of older granite, gneiss, and migmatite. Deeper basement depths of >4 km predominate in the southwestern, central, and northeastern portions of the study area, trending along the trough's axis. These deep zones are filled with Cretaceous sediments that must have accumulated after the Mesozoic development of the Benue Trough's subsided graben structure. Our study estimated scaling exponent ranging from 0 to 2. There were some correlations with the geology of the area, particularly around the crystalline basement complex in the northern portion. Within the central portion of the Middle Benue Trough, however, the source distributions are less correlated, uneven, and not always consistent with the geology of the area. This could be due to the region's dynamic and unstable tectonics, as numerous magmatic intrusions have been emplaced into the Cretaceous sediments at various depths, potentially influencing the scaling exponent values.

Introduction

The magnetic survey method is a rapid and cost-effective geophysical technique for acquiring information about the sub-surface geology of an area based on the anomalies in the earth's magnetic field generated by variations in magnetic properties of the subsurface rocks. Even though most of the rock forming minerals are often non-magnetic, some significant amount of magnetic minerals is often present to generate meaningful magnetic anomalies (Kearey et al., 2002). These magnetic minerals are mainly magnetite and pyrrhotite and are largely responsible for the magnetic characteristics of rocks. Most igneous rocks especially the basic types are very magnetic because of the relatively high magnetic content. The acidic igneous rocks on the other hand are less magnetic because the proportion of magnetite reduces with increasing acidity in igneous rocks (Kearey et al., 2002). In metamorphic rocks, the magnetic behavior varies due to the complex mineral reactions that occur during their formation, while sedimentary rocks are often non-magnetic except where significant amounts of magnetic minerals are present (Gunn, 1997). Magnetic surveying thus has a wide application ranging from small scale engineering to large scale exploration for both local and regional geological purposes. These include exploration for petroleum, precious minerals, geothermal reserves, geological structures, depth estimations, archeological investigation, identification of regions of meteorite impact crater (Ejiga et al., 2022; Ejiga et al., 2019; Ekwok et al., 2019; Hidayah et al., 2018; Ibraheem et al., 2019; Nordiana et al., 2015). Magnetic surveys can be performed either on land, sea or in the air, however, for most regional studies, airborne magnetic survey is preferred. Airborne magnetic survey better known as Aeromagnetic survey are performed using aircraft attached with a magnetometer. Aeromagnetic survey provides a relatively less expensive way to survey a large area or inaccessible area, no matter how remote over a shorter period. This core advantage has made aeromagnetic survey preferred over other geophysical surveys for most regional-scale investigation performed across the globe. These benefits attracted the Nigeria Geological Survey Agency (NGSA) to carry out a nationwide airborne magnetic survey across the entire area of Nigeria landmass, between 2003 and 2009 via a third party exploration company, Fugro Airborne Surveys. The survey was carried out along a NW – SE trending flight lines (perpendicular to the regional geological trend of the area) equally spaced at about 500 m with a tie line spacing of 2 km. The aircraft was flown about 80 m above the mean ground surface to acquire the magnetic data with high resolution. This kind of survey is massive as a total of seven different aircrafts were engaged at every stage of the survey and a total of over 1.9 million line-km of magnetic surveying was performed (Seequent, 2010). Before being stored at the NGSA office, the data were subjected to all necessary magnetic corrections, including the diurnal variations and the international geomagnetic reference field (IGRF), using the 2005 model. Since the release of this high resolution aeromagnetic data (HRAD), there have been keen interest from several researchers to utilize the data for various geological investigations.

Efforts have been made by some researchers to estimate sediments thickness and the basement depths in the Benue Trough and adjoining region through the analysis of HRAD. Most of these works (Ekwok et al., 2021; Ogunmola et al., 2016), however, were based on non-scaling spectral analysis techniques. The non-scaling technique which is based on Spector and Grant (1970) assumes a random and uncorrelated distribution of sources. This was largely due to limited knowledge about magnetic source distribution in the subsurface earth as at that time. However, the source distribution is discovered to correlate from acoustic, density, resistivity, gamma-ray, and borehole, which corresponds to scaling noise (Bansal and Dimri, 2010; Bansal et al., 2011; Maus and Dimri, 1995; Pilkington and Todoeschuck, 1990). This implies that magnetic sources follow a fractal/scaling distribution, consequently, the Spector and Grant (1970) technique is modified by introducing a fractal parameter known as scaling exponent (β) to account for this fractal/scaling distribution (Bansal and Dimri, 2010; Maus and Dimri, 1995, Maus and Dimri, 1996; Pilkington and Todoeschuck, 1990, Pilkington and Todoeschuck, 1993). The scaling spectral technique have been successfully applied in some areas to simultaneously estimate the basement depths and scaling exponents (Abdullahi et al., 2019; Kumar et al., 2018).

By applying this modified scaling spectral technique on HRAD acquired for the Middle Benue Trough (MBT) of Northcentral Nigeria, we present depth estimation to magnetic basement based on scaling/fractal distribution of the magnetic sources of the region. We also estimated the fractal parameters for each corresponding block window of the area. Because most previous studies in the MBT used non-fractal techniques with low resolution magnetic data, we believe this current work will provide a more reliable depth estimation.

Section snippets

Geologic setting

The Nigerian geology generally, is composed of 3 significant petrological groups, which are the Basement Complex, Younger Granites, and Sedimentary Basins (Table 1). The Basement Complex comprises of the Migmatite-Gneiss Complex, the Schist Belts, and the Older Granites which are Precambrian in age (Obaje, 2009). The Younger Granites are a set of Jurassic magmatic ring complexes concentrated mostly in Nigeria's northcentral region. The Sedimentary Basins which include the Benue Trough, are

Scaling spectral method

The power spectrum, P(k) of scaling noise based on observation from borehole data and other sources can be mathematically defined (Pilkington and Todoeschuck, 1990) as:$Pk \propto K^{-\beta}$

Where P(k) is the power spectrum of the magnetization distribution equivalent to the magnetic source, K is the radial wavenumber and β is the scaling exponent which determines the appearance or extent of correlation in spatial statistical distribution within the subsurface crust. Zero value of the scaling exponent relates

Results

Several researchers have suggested varieties of window sizing for depth estimation. Many however, are of the opinion that window size selection should be at least 4 or 6 times the magnetic source depth being targeted (Blakely, 1996; Kumar et al., 2020; Nwogbo, 1998). As a result, we choose a window size of 55 km × 55 km with 27.5 km (50%) overlap, yielding 49 spectral blocks for the entire study region (Fig. 2). By applying the scaling spectral technique, we calculated the depth to magnetic

Discussion and conclusion

The magnetic basement depths beneath the Cretaceous sediments, calculated from our study shows a depth range between 1.8 km to 6.3 km with depth variations of ‘highs’ and ‘lows’ observed across different lithological units around the area of study (Fig. 4). This is because the topography of the basement floor underneath the MBT is believed to be irregular with some uplifted basement blocks that outcrops in few places and intruded by several major and minor intrusives (Ajakaiye, 1981; Cratchley

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3	Noer El Hidayah Ismail	Supervision, Methodology, Resources, Review and editing
4	Mutari Lawal	Field investigation, Validation, Review and editing, Resources, Analysis
5	Nura Abdumumini Yelwa	Field investigation,

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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