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Original Research Article

Depth Estimation Based on Fourier Spectral Analysis of Potential Field Data

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ABSTRACT

The main purpose of using potential field data such as magnetic field data is to make available an enhanced knowledge of subsurface structural study. Depth estimation to magnetic anomalies often assists in mineral, groundwater and hydrocarbon explorations. The study deals with the quantitative interpretation of airborne magnetic data of Auchi sheet (Sheet No. 266), conducted by the Nigerian Geological Survey Agency. The average depth values to buried magnetic sources using the power spectrum of total intensity field were accomplished in parts of Edo north district of Edo State, Southern Nigeria using spectral analysis. These depths were established from the slope of the log-power spectrum at the lower end of the total wave number or spatial frequency band. The analysis of aeromagnetic data was construed using fast Fourier transform (FFT) in Oasis Montaj software. In order to reduce aliasing error, the aeromagnetic data was gridded at spacing of 2 km. It was showed from the radially average power spectrum depth estimated curve that, the depth to the magnetic sources in the area ranged from shallow 50 m to intermediate 200 m to deeper 1500 m. The variation in magnetic depth values shows common inclinations in the magnetic basement surfaces.

1. INTRODUCTION

Aeromagnetic surveys underscore the identification and interpretation of deformational features such as fractures, shearing, faults and joints as a possible host or passage channels when exploring for minerals resources (Porwal et al., 2006; Schetselaar and Rhyan, 2009; Okpoli and Eyitoyo, 2016), hydrocarbons and groundwater (Ilugbo and Ozegin 2018). Deformational features are often attributed to a sudden discontinuity of the magnetic unit, offsets of apparently similar magnetic units, an abrupt change in depth to magnetic sources, magnetic anomalies pattern and geometry of magnetic sources (Gunn *et al.,* 1997). These zones may serve as potential hosts for a variety of minerals and may be used as guidance for exploration of the epigenetic, stress-related mineralisation in the surrounding rocks (Revees, 2005). Aeromagnetic surveys employ a non-destructive method that measures the susceptibility contrast of subsurface rocks. Therefore airborne magnetic surveys are useful in mapping geologic structure on or inside the basement rocks or to detect magnetic minerals directly which reflect the lateral variations in the earth's magnetic field (Burger *et al*., 2006). These variations are connected to alterations of structures, magnetic susceptibility or remanent magnetisation. Fourier spectral analysis in recent years has become a widely utilized tool for the processing and interpretation of potential field data. It is particularly well suited to the analysis of aeromagnetic maps and profiles, where coverage commonly is of broad scope and statistical treatment is appropriate (Olowofela *et al.,* 2013).

Depth estimation is best resolved by establishing the shape and size of the anomaly (Nwugha *et al*., 2019). Depth estimation from potential field power spectrums (spectra) requires a pragmatic supposition of the statistical characteristics of the source distributions. The power spectrum analysis answers the question "How much of the signal is at a frequency?" This accounts for any process that quantifies the various amounts of light, sound and radio waves versus frequency. Revees (2005) stated that the depth factor invariably dominates the shape of the radially averaged power spectrum of magnetic data. In this regard, 'radially averaged' means that the powers for equal lengths of the wave vector are averaged; which has shown fitting interpretation of the power spectrum of potential field data. The radially averaged power spectrum of the field in a 2-D observation plane decreases with increasing depth to source t by a factor $\exp(-2tr)$, r being the wave number. Hence, if the depth factor dominates the shape of the power spectrum, the logarithm of the power spectrum should be proportional to $-2tr$, and the depth to source can be derived directly from the slope of the log radially averaged power spectrum. Since the latter is usually curved, a single power spectrum may yield up to five depth values (Maus and Dimri, 1996). A broad range of spectral techniques has been anticipated to detect the depth to the base of the magnetic layer of the lithosphere from near-surface magnetic anomalies (Negi *et al.,* 1987). Spectral analysis of potential field data has been used extensively over the years to derive the depth of certain geological features, such as magnetic basement (Garcia-Abdeslem and Ness, 1994; Olowofela *et al.,* 2013).

Edo North Senatorial district of Edo State, Southern Nigeria and its adjoining areas has experienced several geophysical investigations, viz; electrical resistivity techniques - vertical electrical sounding and horizontal profiles studies, electromagnetic surveys - VLF (very low frequency) and borehole logging whose aim vary from determination of mineral potential of the area, mapping of the geological and stratigraphic setting, to highlighting the tectonic framework of the area (Ozegin *et al.,* 2011; Ozegin and Oseghale 2012; Kehinde *et al*., 2013; Nwugha *et al*., 2019), but little has been done in the area of aeromagnetic exploration Hence the aim of this study is to provide information on depths to magnetic sources from aeromagnetic data using Fourier spectral analysis technique.

2. MATERIALS AND METHODS

2.1. Description of Study Area

The study area is located between longitudes 6°00' E and 6°30' E and latitudes 7°00' N and 7°30' N (Figure 1). The study area is generally accessible and motorable. The availability of both tarred and untarred roads as well developed footpaths provides easy access to the area and to the outcrops. The topography is generally undulating with Eastward highlands of granitic origin. (Kogbe,1989). The geology of the study area is a basement complex belonging to Igarra schist belt of Southwestern Nigeria which is characterised by a complex geological framework made of different structures and rocks. Rahaman (1988) noted that the south western basement complex of Nigeria lies within the rest of the Precambrian rocks in Nigeria. He grouped the rocks in this area as migmatite – gneiss complex comprising largely of sedimentary series with associated minor igneous rock intrusions which have been altered by metamorphic, migmatitic and granitic processes.

Odeyemi (1981) suggests that almost all the foliation exhibited by rocks of southwestern Nigeria excluding the intrusives are tectonic in origin, because pre-existing primary structures have been destroyed by-subsequent deformation.

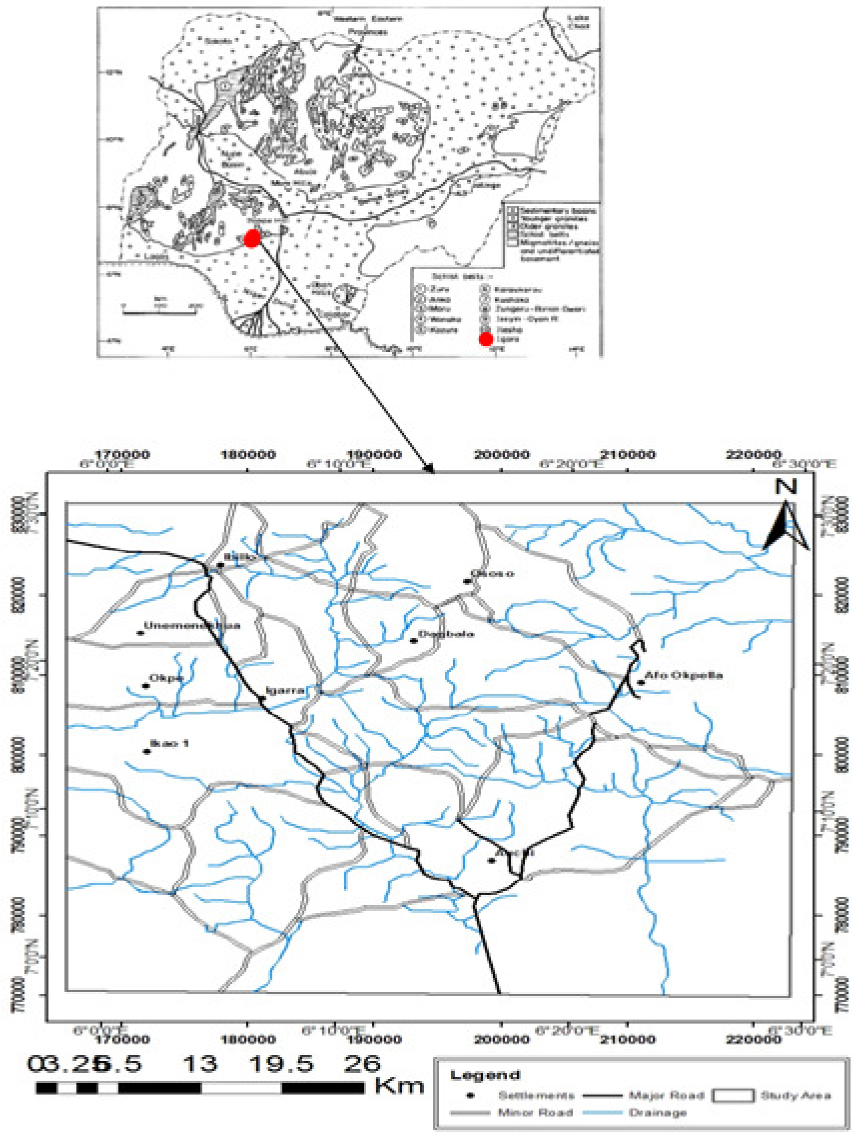

Figure 1: Map of Nigeria showing the study area

2.2. Data Collection

The aeromagnetic data was acquired at a nominal flying altitude of 152 m (about 506 ft) with flight lines spaced 2 km in the direction 60/240 (dip/azimuth) degree and contour interval of 20 nT using magnetometer aboard or towed behind an aircraft (Burger *et al*., 2006). It measures Earth's magnetic field intensity to an accuracy of 0.1 nT using magnetometers. Aeromagnetic map on a scale of 1:100,000 was acquired from the Nigerian Geology Survey Agency (NGSA). The processed airborne magnetic field intensity was enhanced through the removal of the International Geomagnetic Reference Field (IGRF) over the area. Qualitative and quantitative interpretations were utilized in this work. Qualitative interpretation of the field data was first carried out by inspecting the total magnetic intensity (TMI) grid of the study area. Kearey *et al.* (2002) affirmed that qualitative interpretation of magnetic map is one of the initial stages of interpretation, involving the acknowledgment of diagnostic shapes, trends of anomalies that can be related to geologic structures or rock units. The total magnetic intensity map of the area was produced into maps which are in colour aggregate. The preliminary stages of qualitative magnetic data interpretation involved the application of mathematical filters, namely; map reduction to the equator (RTE) and upward continuation map to observed data. The specific goals of these filters vary, depending on the situation. The common purpose is to improve anomalies of interest and/ or to gain some fundamental information on source location or magnetization (Nabighian *et al.,* 2005). The RTE removes the asymmetry and declination effect to conserve low angle of inclination at the equator while the upward continuation operation smoothen the anomalies obtained at the ground surface by projecting the surface mathematically upward above the original datum (Revees, 2005). Quantitative interpretation of the magnetic data requires estimating the expected depths to the magnetic sources in the study area. This was achieved by applying spectral analysis (radial average power spectrum). The depths to the magnetic basement make available information on the configuration of the basement. The spectral analysis of potential field data which served as an approximate guide in estimating the depth of magnetic sources was adopted for this research. The average radial power spectrum was calculated using fast Fourier transform (FFT).

2.3. Depth Estimation from Potential Field Power Spectrum

The power spectrum reveals the existence, or the absence, of repetitive patterns and correlation structures in a signal process (Saeed, 2000). These structural patterns are extensively employed for many applications in pure and applied sciences, engineering and mathematics. The commonest method of spectral estimation is based on the fast Fourier transform. In this analysis, the residual is transformed from space to the frequency or wave number domain via FFT algorithm application. This art generates the spectral energy curve from which the depth values relating the deeply seated and shallow related magnetic features can be calculated by fitting lines on the high and low frequency components (Blanco-Montenegro *et al.*, 2003). FFT is an algorithm for efficient computation of the discrete Fourier transform (DFT) of a sequence (or its inverse). Fourier analysis converts a signal from its original domain (often time or space) to the frequency domain and vice versa. An FFT rapidly computes such transformations by factorizing the DFT matrix into a product of sparse (mostly zero) factors. In this research, spectral analysis was done using interactive filtering in Oasis Montaj MAGMAP extension, which is frequency domain processing of most potential field data. Oasis in-built MAGMAP tool possesses is a powerful mathematical imaging technique that supports the application of two Dimensional Fast Fourier Transform (2D-FFT) filters to gridded data. After preparing the magnetic grid (in space domain), it was then transformed to wave number (frequency) domain using forward filtering transform filters, i.e. the approaches used involve Fourier transformation of the digitized aeromagnetic data to compute the energy (or amplitude) spectrum. The FFT decomposed the residual into its frequency components and energy spectral segments. Log of the energy spectral was thus plotted against the radial frequency component.

The plot estimates was used as a guide to the depth of magnetic source populations. The depth to a statistical ensemble of sources is determined by the expression

$$h = -s/4\pi \tag{1}$$

where h is depth and s is the slope of the log (energy) spectrum.

The slopes of the segments yield estimates of average depths to magnetic sources of anomalies. Given a residual magnetic anomaly map of dimensions l x l, digitized at equal intervals, the residual total intensity anomaly values can be expressed in terms of a double Fourier series expression given as:

$$T(x, y) = \sum_{n=1}^{N} \sum_{m=1}^{M} P_m{}^n \cos\left(\frac{2\pi}{D}\right)(nx + my) + Q_m{}^n \sin\left(\frac{2\pi}{D}\right)(nx + my) \tag{2}$$

Where D is dimensions of the block, $P_m^{\ n}$ and $Q_m^{\ n}$ is the Fourier amplitude and N and M are the number of grid points along the x and y directions respectively.

In the same way, using the complex form, the two dimensional Fourier transform pair derived in the wave number domain, since it involves the calculation of derivatives of magnetic anomalies may be written as:

$$f(x,y) = \frac{1}{4\pi}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f^{-}(\mu,\nu).\ell^{\,i(ux+vy)}\, d\mu dy \qquad \text{(Space domain)} \tag{3}$$

$$\bar{f}(\mu,\nu) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f(x,y).\ell^{-i(\mu x - vy)}\, dxdy \qquad \text{(Wave number domain)} \tag{4}$$

Where μ and v are wave numbers in the x and y directions respectively; these are measured in radians per metres (Geosoft, 2005). The transformation procedures involved application of different filtering functions. In this study, the upward continuation and reduction to the equator were applied.

3. RESULTS AND DISCUSSION

The process implemented for data analyses are qualitative approach - involves map examination of upward continuation map and reduction to the equator while quantitative approach - entails depth computation of radial average power spectrum.

3.1. Upward Continuation Map

Figure 2 shows the upward continuation of the processed TMI reduced to equator over the study area continued upward to 100 m. The anomaly patterns identified in Figure 2 are a qualitative representation of spatial variation in the magnetic properties of deep basement rocks and structures in the area. In physical terms, as the continuation distance is increased, the effects of smaller, narrower and thinner magnetic bodies (A and B) in Figure 2 progressively disappear relative to the effects of larger magnetic bodies of considerable depth extent. As a result, upward-continuation maps give the indications of the main tectonic and crustal blocks in an area. It should be noted that upward continuation methods are used in magnetic interpretation to define the form of regional potential field variation over a survey area; this is because the proliferation of local magnetic anomalies often obscures the regional picture, but upward continuation is used to smooth out these disturbances without repairing the main regional features (Mushayandebvu *et al.,* 2004), since the regional field is assumed to originate from relatively deep-seated structures (Ilugbo and Ozegin 2018).

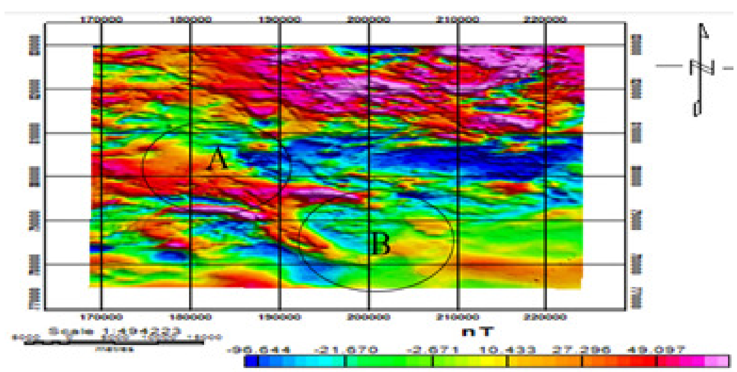

Figure 2: Upward continuation map

3.2. Reduction to the Equator

Figure 3 shows the reduction to the equator map. The RTE map helps to remove magnetic declination effect in the low magnetic latitude region by centering the peaks magnetic anomalies over their sources thereby improving on structural features and its orientations. Due to the fact that the magnetic data were acquired at the magnetic low latitude and were reduced to the equator, low magnetic values indicate high magnetic susceptibility while the high magnetic values indicate low magnetic susceptibility values (John and Emmanuel, 2014). Two major magnetic zones were identified based on the magnetic intensity variation over the study area. The northwestern and northeastern parts are dominated by high amplitude magnetic anomalies values (between 26.883 nT and 106.943 nT) and the southeastern part characterised by relative low amplitude magnetic intensity values (between -74.747 nT and -25.736 nT) marked with greenish to blue colour shown a contrast that is assimilated to a channel between the Pan-African Mobile Belt (PAMB) of Central Africa and the Congo Craton. Thus, the Northeastern part characterized by the positive anomaly values seems to correspond to the PAMB (Owono *et al.,* 2019). The tectonic facts put in evidence through the qualitative analysis of the RTE map are witnessing the fact that the study area has been affected by intense folding events.

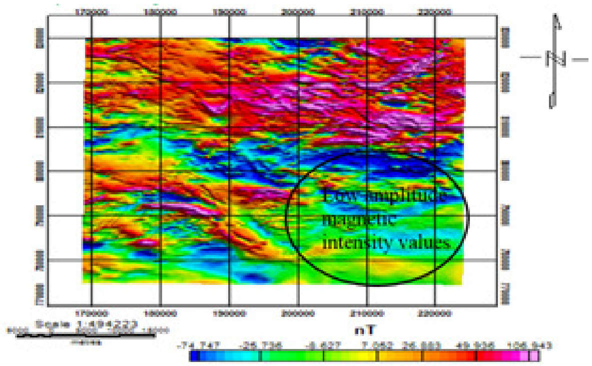

Figure 3: Reduction to the equator

3.3. Radial Average Power Spectrum

The Figure 4 depicts the radial spectrum and depth estimate plots from the aeromagnetic data. Fourier spectral analysis was applied on the RTE aeromagnetic survey data to calculate the energy spectrum. The depths to the top of deformational sources that produced the observed anomalies in the magnetic map were determined using spectral analysis. As a result, radial power spectrum curve was generated (Figure 4). From the observed spectrum, (i.e. change in the slope of the spectrum curve), the spectrum consist of the deep origin or regional component (low frequency characterized by longer wavelength anomaly), intermediate and the shallow origin or near-surface component high frequency characterized by short wavelength anomaly). It shows a typical radial averaged spectrum of the digitised aeromagnetic data of the study area and the depth estimate plot. The theoretically average power spectrum of the study area shows a normal plot that has straight line segments which decreases in slope with increasing frequency. From the radially average power spectrum depth estimated curve, the depth to the magnetic sources in the area ranged from shallow 50 m to intermediate 200 m to deeper 1500 m (Figure 4). The depth of the basement anomalies in the area agrees with the findings of (Nwugha *et al.*, 2019).The shallow and intermediate sources perhaps signify depths to Precambrian basement or near surface igneous intrusive rocks with remnant magnetism. The deeper sources typified by high negative anomaly values having longer wavelength portrays basic intrusive rock at depth or intruding dike at depth. All the anomalies delineated are believed to be potential targets for subsequent exploration activities to determine the viability for exploitation. This suggests that the major fractures and faults in the study area are deep within the basement formation (Okpoli and Eyitoyo, 2016), since the spectral analysis enhances the anomalies associated with deep magnetic sources at the expense of the dominating intermediates magnetic sources. The anomalies delineated are believed to be potential targets for successive exploration activities to determine the viability for exploitation.

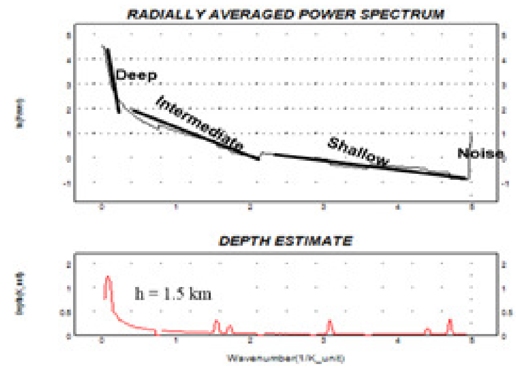

Figure 4: Radial spectrum and depth estimate plots from the aeromagnetic data

4. CONCLUSION

Fourier spectral analysis was used to determine depth to geological structures of the study area from aeromagnetic datasets collected over the area. The magnetic image enhancing filters applied to the residual magnetic intensity were upward continuation and reduction to the equator using Geosoft Oasis Montaj package. From the radially average power spectrum depth estimated curve, the depth to the magnetic sources in the area ranged from shallow 50 m to intermediate 200 m to deeper 1500 m. The shallow and intermediate sources possibly signify depths to Precambrian basement or near surface igneous intrusive rocks with remnant magnetism. The deeper sources characterized by high negative anomaly values having longer wavelength showed basic intrusive rock at depth or intruding dike at depth. These results also demonstrate the reliability of radial spectral analysis of magnetic interpretation in estimating the depth to the surface of the magnetic sources in basement complex.

5. ACKNOWLEDGEMENT

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6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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