

Comparative Depth to Magnetic Source Analysis of Shanga (Sheet 96), North-western Nigeria Using Aeromagnetic Data

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Abstract

The depth to magnetic sources and sedimentary thickness within the study area have been estimated using the recently acquired high-resolution aeromagnetic data (HRAD) of Shanga, sheet 96, north-western Nigeria, which is bounded by longitudes 4° 30' 00" E to 5° 00' 00" E and latitude 11° 00' 00" N to 11° 30' 00" N and covers approximately 3025 km². To achieve the goals, three methods were used: the analytic signal method, the Euler deconvolution method and source parameter imaging (SPI). A range of depths between 11.457 m and 1314.409 m have been measured utilizing analytical signal and source parameter imaging techniques. The boundary between the research area's sedimentary basin and basement regions was made clear by the results of these two techniques, which were essentially similar. The study area's shallow sources are found in the east where outcropping basement rocks are present and the overburden thickness is minimal (0–71.968 m), whereas the deep sources are found in the southwest where the sedimentary cover is present and is rather thick (1314.409 m). There were four (4) for the 3D Euler solutions. Depths 200 m, between 200 and 400 m, between 400 and 600 m, and >600 m, but the most peculiar feature of all the Euler solutions is that solutions with shallow depths characterized the basement part of the study area while solutions with depths >600 m characterized the sedimentary portion of the study area. According to the maps, where the outcropping basement rocks could be found, the depths determined using the three methods were increasing towards the southwestern half of the maps and decreasing towards the eastern side.

Keywords: Depth, Overburden, Euler Deconvolution, Analytic Signal, Sedimentary Basin.

Introduction

The present study involves a comparative analysis of depth to magnetic sources within Shanga and environs using airborne magnetic data. To ascertain the depth of the magnetic basement beneath the sedimentary cover, aeromagnetic data analysis is a viable method. An essential factor in the quantitative interpretation of the anomalous body is its depth. Several well-known techniques for determining magnetic basement depths include the ones listed below: The slope technique serves as the basis for the empirical analysis (maximum and half-slope), the spectral method, the source parameter imaging techniques (SPI), the Werner deconvolution method, the Euler deconvolution method, the analytic signal (AS), and the DEXP method. Peter's half-slope method, which produces more precise

estimates, is faster and easier than model curve fitting analysis, according to Peters (1949) and Milsom (2003). Bhattacharyya and Leu proposed the spectrum approach in 1975, and the designed methods enable the computation of the DBMS that might be connected to the Curie point depth (Bansal *et al.* 2011). Additionally, by assuming two-dimensional targets, the Werner deconvolution is an automatic depth estimation method that has mostly been limited to profile data. Werner (1955) developed the method for determining whether the effects of adjacent anomalies may be attributed to thin sheets or not. By taking the horizontal derivative of the observed profile and assuming that the causative bodies are both two-dimensional and have polygonal cross-sections, this can be achieved. The approach was invented by Hartman *et al.* (1971), and then modified by Jain (1976), Tsokas and Hansen, (1996). The technique was first applied to several 2D sources by Hansen and Simmonds (1993), and it was first applied to multiple 3D sources by Hansen (1994). Euler deconvolution was put forward by (Reid *et al.*, 1990), the Source parameter imaging "SPI" (Thurston and Smith, 1997), Analytic signal (AS) (Nabighian, 1972) and DEXP method (Fedi 2007; Abbas and Fedi 2014). In this investigation, three methods of assessing depth to magnetic sources have been compared in a quest to unravel depth to magnetic sources by applying analytic signal, 3D Euler deconvolution, and source parameter imaging techniques.

Several articles have been published within the Nigerian basement complex for determination of depth to magnetic source, employing either Euler 3D or Spectral or source parameter imaging or both techniques (Abdulsalam *et al.*, 2022; Lawal *et al.*, 2021; Tawey *et al.*, 2020a; Usman and Jibril 2020; Sadiq and Zarman, 2019; Sani *et al.*, 2019; Osagie *et al.*, 2018; Nur *et al.*, 2011; Opara *et al.*, 2015; Ofoegbu and Hein, 1991).

Statement of the Problem

For a variety of geological, geophysical, and resource exploration reasons, knowledge of the depth to magnetic sources beneath the Earth's surface is crucial. However, some of the methods and techniques utilized to calculate this depth occasionally include presumptions and oversimplifications that could result in inaccurate depth estimates. To better understand subsurface geological structures, mineral deposits, and other geophysical phenomena, it is necessary to compare several methods used in depth to magnetic source estimation to determine among the techniques used, the more accurate and reliable method for determining the depth of magnetic sources from the surface. As a result, we have examined the outcomes of three established approaches for estimating the depth of magnetic sources: Euler deconvolution, source parameter imaging (SPI), and analytic signal depth estimation (AS) methods.

Objectives of the Study

The objectives of the study are to Carry out depth analysis using;

- a) The Analytic Signal (AS) method

- b) Source Parameter Imaging (SPI)
- c) Euler Deconvolution and;
- d) Compare the results from the three methods used

Location, Geology and Tectonic Settings of the Study Area

The research area is situated in the north-western region of Nigeria and falls within two states (Niger state and Kebbi state) with a boundary between longitude $4^{\circ}30'$ E to longitude 5° E. The study area is in the northwest of Nigeria, between t Niger and Kebbi states, and has a boundary between longitudes $4^{\circ}30'$ E and $5^{\circ}00'$ E and latitudes $11^{\circ}00'$ N and $11^{\circ}30'$ N (Figure 1).

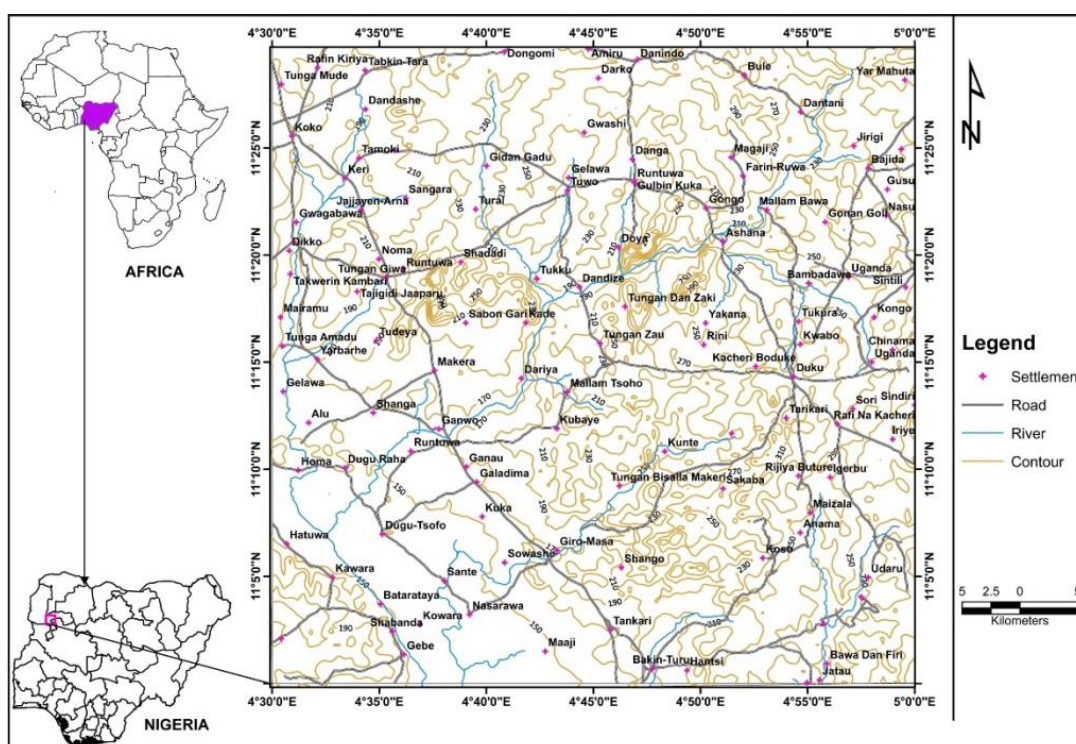


Figure 1: Location map of the study area

The study area is partly basement (NGSA, 2006; Obaje, 2009) and sedimentary (part of Iullemeden Basin), with topography that ranges from 132 m for low elevated areas, particularly areas around the south-western portion of the map (Koko, Tungan Magaje, Shanga, Dugu Tofo, Ganwo, and Nasarawa), to 352 m for elevated areas according to analyses of the study area's Digital Elevation Model (DEM), (Figure 2). The Nigerian basement complex is part of the Pan-African mobile belt and is situated between the West African and Congo Cratons, south of the Tuareg Shield (Black, 1980). The Mesozoic calc-alkaline ring complexes (Young Granites) of the Jos Plateau have intruded it, and it is unconformably overlain by Cretaceous and younger sediments. The Nigerian basement was affected by the Pan-African orogeny (600 Ma) and occupies a reactivated area formed

by a plate collision between the passive continental margin of the West African craton and the active continental margin of the Pharusian (Dada, 2006; Burke KC, Dewey, 1972). The basement rocks are thought to be the product of at least four major orogenic cycles of deformation, metamorphism, and remobilization, which correspond to the Liberian (2,700 Ma), Eburnean (2,000 Ma), Kibaran (1,100 Ma), and Pan-African cycles of deformation, metamorphism, and remobilization (600 Ma).

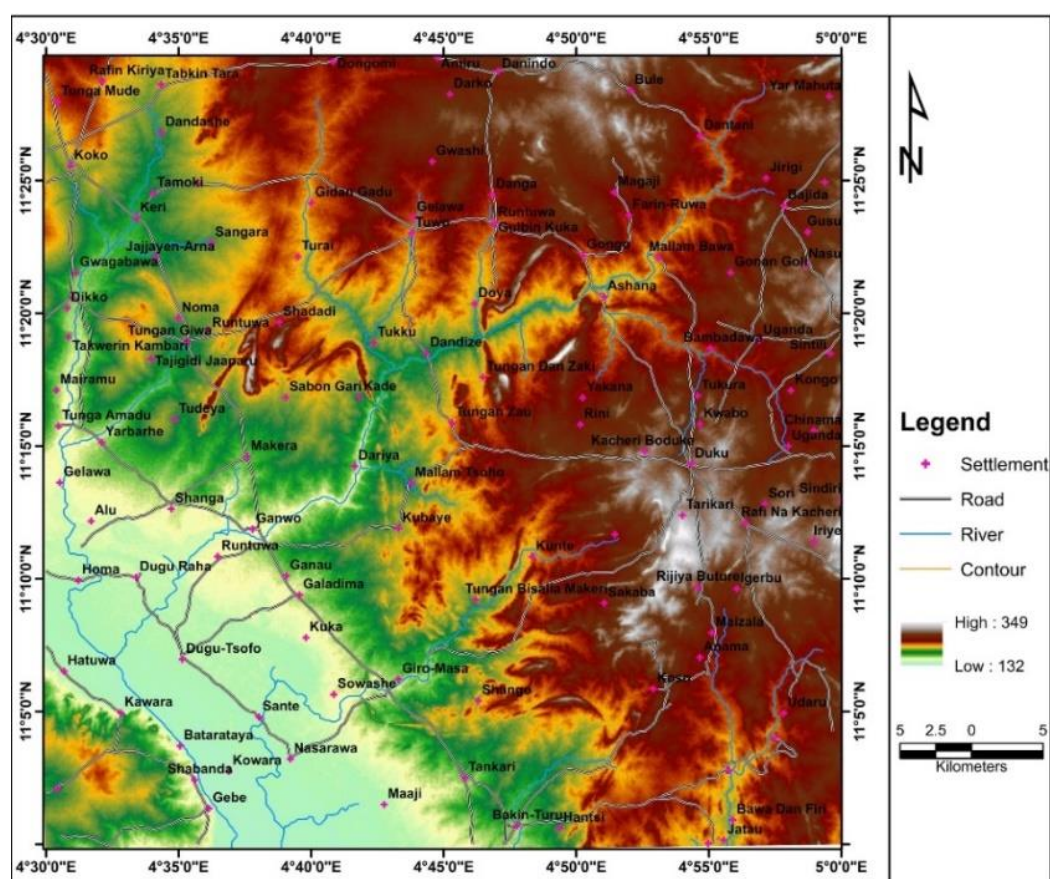


Figure 2: Digital Elevation Model of the Study Area showing the Topographic Variation

The first three stages were marked by extreme deformation and isoclinal folding, as well as regional metamorphism, and were accompanied by substantial migmatization. Following the Pan-African deformation, regional metamorphism, migmatization, and widespread granitization and gneissification occurred, creating syntectonic granites and homogeneous gneisses (Abba, 1983). Late tectonic placement of granites and granodiorites, as well as related contact metamorphism, followed the final stages of this last deformation. The orogeny came to an end with faulting and fracturing (Olayinka, 1992; Gandu *et al.*, 1986). Within Nigeria's basement complex, four important petro-lithological units can be distinguished: a. the Migmatite-Gneiss Complex (MGC), b. the Schist Belts (Metasedimentary rocks and Metavolcanics), c. the Older Granites (Pan African granitoids), and d. Undeformed acid and Basic Dykes.

The Iullemeden Basin is an intracratonic epeirogenesis basin that stretches from the crystalline areas of Adrar des Iforas, Ahaggar, and Ar (Niger Republic) in the north to the Gusau-Kano region (Nigeria) in the south. It has a gross land area of more than 700,000 km². The Sokoto Basin is an embayment of the Iullemeden Basin, situated in the Iullemeden Basin's southeastern corner and northeast of Nigeria (Odebode, 2010).

Sokoto Basin is a young (Mesozoic-Tertiary) West African inland cratonic sedimentary basin (Obaje, 2009; McCurry, 1976). The basin, like other intra-continental basins in the region and on the African continent in general, formed as a result of epeirogenic warping of technically stabilized crust stretching and rifting. These movements began around the beginning of the Paleozoic and continued into the Upper Cretaceous, and they were primarily responsible for the southwestern propagation of sediments deposited within the basin (Kogbe 1979 and 1981).

Rocks within the study area include fine-grained biotite granite, medium-grained biotite granite, River Alluvium, biotite gneiss, Augene gneiss, undifferentiated Schist including phyllites, Quartzite and Quartz schists, Quartz and mica schists, sandstones, siltstones and clays, sandstones, and siltstones and Migmatitic granite gneiss and Migmatite (Fig. 2).

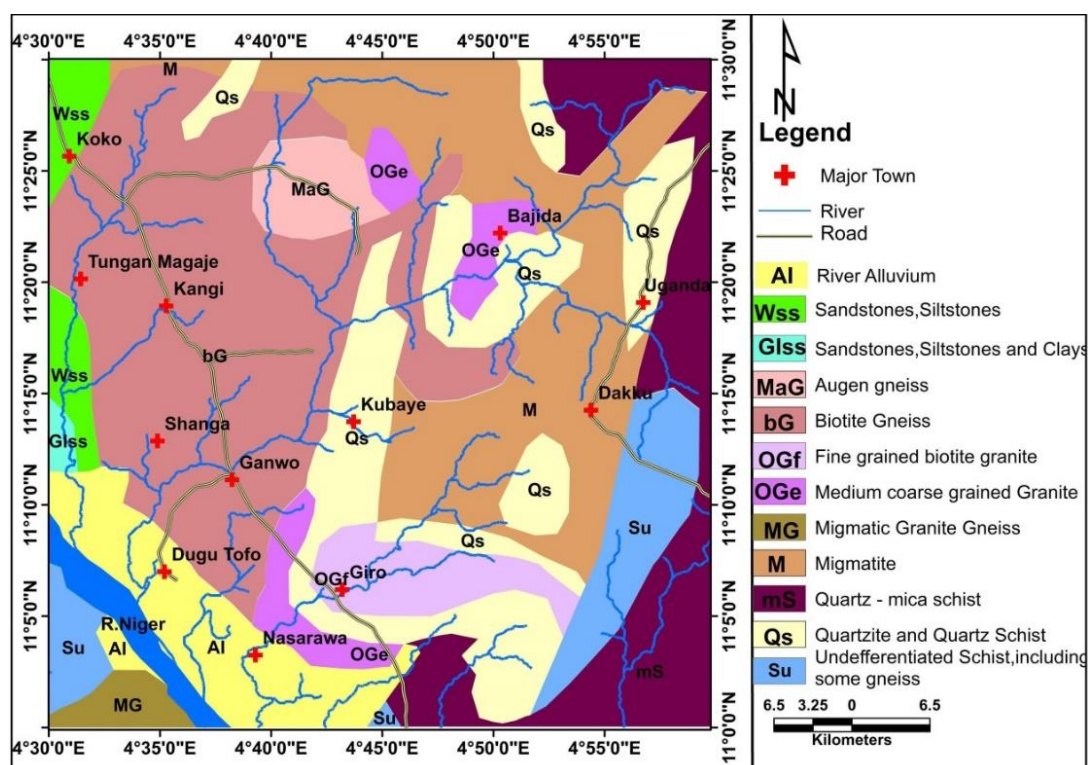


Figure 3: Geologic map of the area (Adapted from NGSA, 2006)

Source of Aeromagnetic Data

The magnetic data used in this present analysis is a higher resolution data collected by the Fugro Airborne Survey for Nigeria Geologic Survey Agency (NGSA) that covers parts of Nigeria in 2009. The survey covered 826,000 km in a series of northwest-to-southeast flight

lines of magnetic surveys that were flown at a line spacing of 500 m and terrain clearance of 80 m. The NGSA provided gridded aeromagnetic data used in this research and the total magnetic field was the parameter determined by Fugro during the airborne survey.

Methods

Analytic Signal Method

The AS is an essential technique used in detecting the boundaries of high and low magnetic features close to the magnetic equator Ansari and Alamdar (2009). The AS technique also centres the peaks of the magnetic source anomalies over their respective causative sources at both high and low-latitude regions Beard and Goitom, (2000). The technique is independent of the direction of magnetisation, and it is slightly affected by noise (Macleod *et al.*, 1993). The AS technique can be defined mathematically in a statement as the square root of the sum of the squares of vertical and horizontal derivatives of a magnetic field as in equation 1:

$$|A(X, Y)| = \sqrt{\left(\frac{\delta T}{\delta x}\right)^2 + \left(\frac{\partial T}{\partial y}\right)^2 + \left(\frac{\delta T}{\delta z}\right)^2} \quad 1$$

where A (x, y) is the amplitude of the analytic signal at (x, y) and T is the magnetic anomaly that is observable at (x, y) Phillips, (2000) and more so, the AS technique is capable of estimating depths of magnetic sources over the study location. The depth estimate depends on the source geometry known as the structural index (SI) of the anomaly of interest Baranov, (1957).

The depths of the magnetic sources are estimated under the assumption that the anomalies are in two dimensions (2-D). Hence, the depths of the magnetic source anomalies are estimated as given in the equation below:

$$AS1 = \sqrt{\left(\frac{\delta fv}{\delta x}\right)^2 + \left(\frac{\partial fv}{\partial y}\right)^2 + \left(\frac{\delta fv}{\delta z}\right)^2}$$

$$2 \ D = \frac{AS}{AS1} * N$$

where,

fv = First vertical derivative of the residual map,

D = Depth to the magnetic sources,

AS = Analytic signal of the residual grid,

AS1= Analytic signal of the first vertical derivative of the residual grid.

N = 1 (contact), N = 2 (dike), N = 3 (pipe), and N = 4 (sphere) (Baranov, 1957).

Euler Deconvolution Method

Within the study area, the Euler Deconvolution method (Reid *et al.*, 1990; Thompson, 1982) was used to determine the shape and depth of magnetic anomaly sources. The 3D Euler's equation can be shown as follows:

$$(x - x_0) \frac{\delta T}{\delta x} + (y - y_0) \frac{\delta T}{\delta y} + (z - z_0) \frac{\delta T}{\delta z} = N(B - T) \quad 3$$

where (x_0, y_0, z_0) is the position of a magnetic source whose total field T is detected at (x, y, z) . B is the regional field value, and the degree of homogeneity is interpreted as the structural index (SI) which is a measure of the rate of change at field distance represented by N , and this structural index has been chosen according to the background knowledge of the source geometry. For this study, four structural indexes ($S_1 = 0, 1, 2$ and 3) for contacts, faults dyke and spheres and horizontal bodies have been used.

Source Parameter Imaging (SPI) Method

The Source Parameter Imaging (Thurston and Smith, 1997) approach estimates magnetic source depths using a profile or grid. The method makes use of the link between source depth and the observed field's local wavenumber (k), which can be determined for every location within a grid of data using horizontal and vertical gradients, as shown in equation (2).

$$K(x, y) = \frac{1}{|A(x, y)|^2} \left(\frac{\partial^2 T}{\partial x \partial z} \frac{\partial T}{\partial x} + \frac{\partial^2 T}{\partial y \partial z} \frac{\partial T}{\partial y} + \frac{\partial^2 T}{\partial z^2} \frac{\partial T}{\partial z} \right) \quad 4$$

$$Depth_{(x=0)} = \frac{1}{K_{max}} \quad 5$$

where $|A(x, y)|^2$ is the square of the analytic signal amplitude. For the dipping contact, the maxima of k are located directly over the isolated contact edges and are independent of the direction of the magnetic field. The depth is estimated at the source edge from the reciprocal of the local wavenumber.

Results and Discussions

Figure 3a represents the total magnetic intensity map of the study area while Figure 3b represents residual magnetic intensity (RMI) reduced to the pole (RTP). From Figure 3a, magnetic intensity values vary from 33001.6 nT low to 33111.539 nT high. The magnetic highs are predominant around the southwestern part of the map while the magnetic lows are observed around the northeastern part of the study area. There is also an observed alternating occurrence of magnetic high and low which are attributed to the presence of deep-seated structures within the study area. Also, the RMI reduced to the pole map (Figure 3b) has a magnetic intensity that varies from -52.204 nT low to 37.503 nT high. Peculiar characteristics in this map are the reverse in magnetic intensities across the study area (Figure 3b). Areas that were low in the TMI map are shown high in the RTP map (Figures 3a and 3b). The Reduction to the Pole (RTP) operation was applied to remove the deviance and directional shift of anomalies induced by a deviation of the magnetization path from the north (Baranov, 1957) which was what led to the reverse in the magnetic intensity in the RTP map.

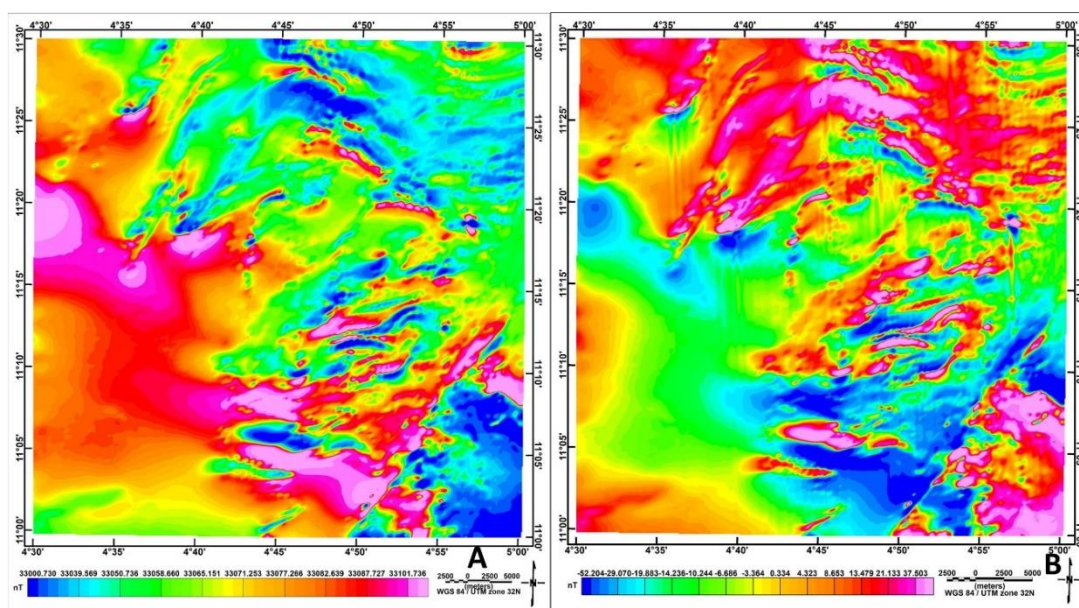


Figure 3: a. Total Magnetic Intensity map (TMI) b. Residual magnetic Intensity (RMI) Reduced to the Pole (RTP)

Analytic Signal Depth Determination

The analytic signal depth of the study area was determined using the analytic signal of residual anomaly (Figure 4a), the first vertical derivative (Figure 4b), and the analytic signal of the first vertical derivative (Figure 4c), while (Figure 4d) represent the analytic signal depth. The analytic signal method is good in the identification of source location and boundary and in locating the magnetization of a magnetic source. From fig. 4a, the southeast, east and northeastern parts of the study portion of the study area are characterized by high analytic signal (0.203 nT/m) which is typical of basement complex or shallow depth to the basement while the southwestern portion of the map having very low analytic signal of 0.002 nT/m is typical of sedimentary basins or areas with very thick sediments cover. The FVD map figure 4b reveals the short frequency anomalies that are typical of basement rocks around the eastern part of the study area. The analytic signal of the first vertical derivative map figure 4c separates the basement part of the study area from the sedimentary part just like the analytic signal map figure 4a. Depth within the study area as revealed by the analytic signal map (figure 4d) shows that depth within this area ranges from -11.745 m to -1267.121 m.

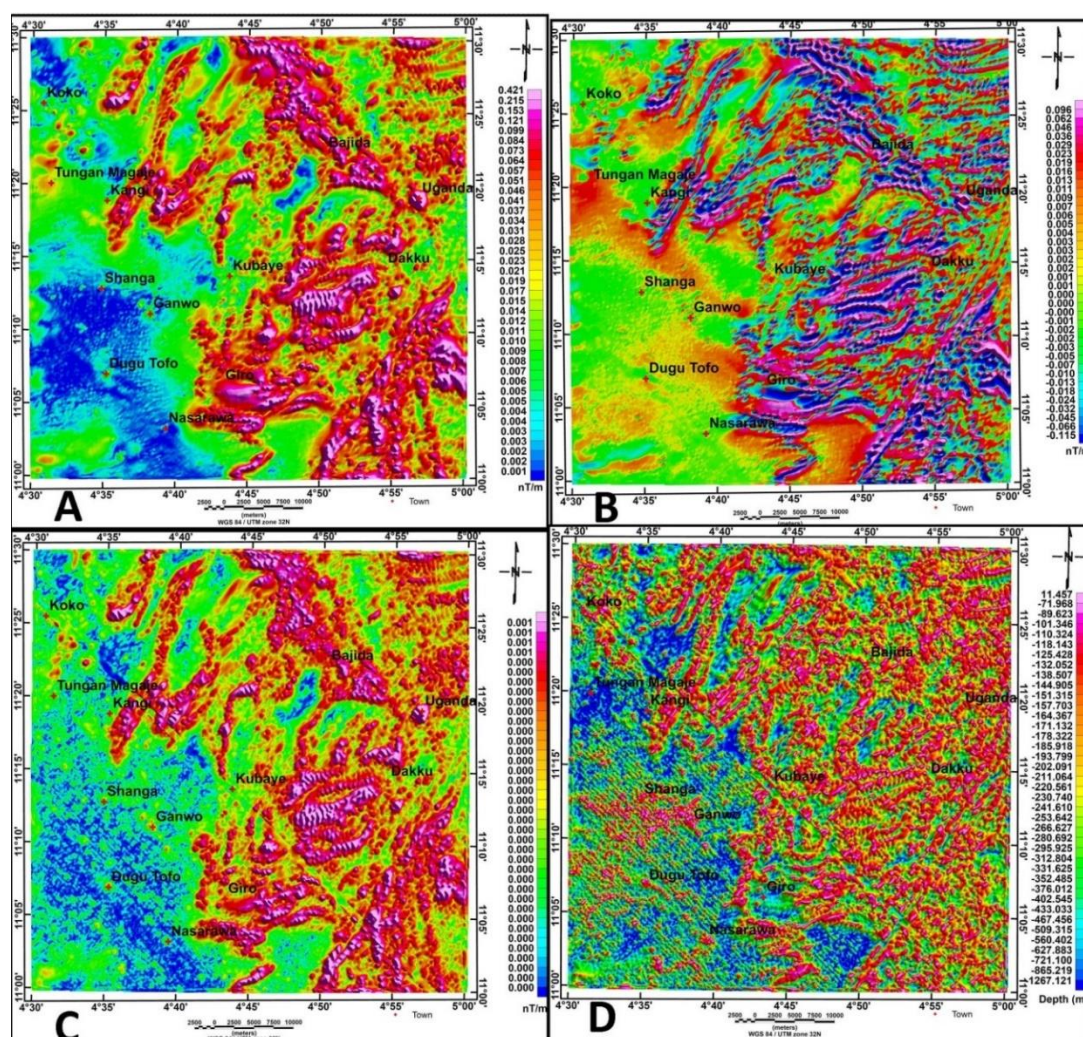


Figure 5: a. Analytic Signal of Residual anomaly b. First Vertical Derivative of Residual anomaly c. Analytic Signal of First Vertical Derivative and D. Analytic Signal Depth

Source Parameter Imaging (SPI) Method

The map produced (Figure. 5) reveal the depth to magnetic sources or sedimentary thickness across the study area. Depth with the study area varies from -15.042 m shallow to 1314.409 m deep. Depth can be said to be increasing toward the southwestern portion of the map and decreases toward the northeastern part of the study area (Figure. 5)

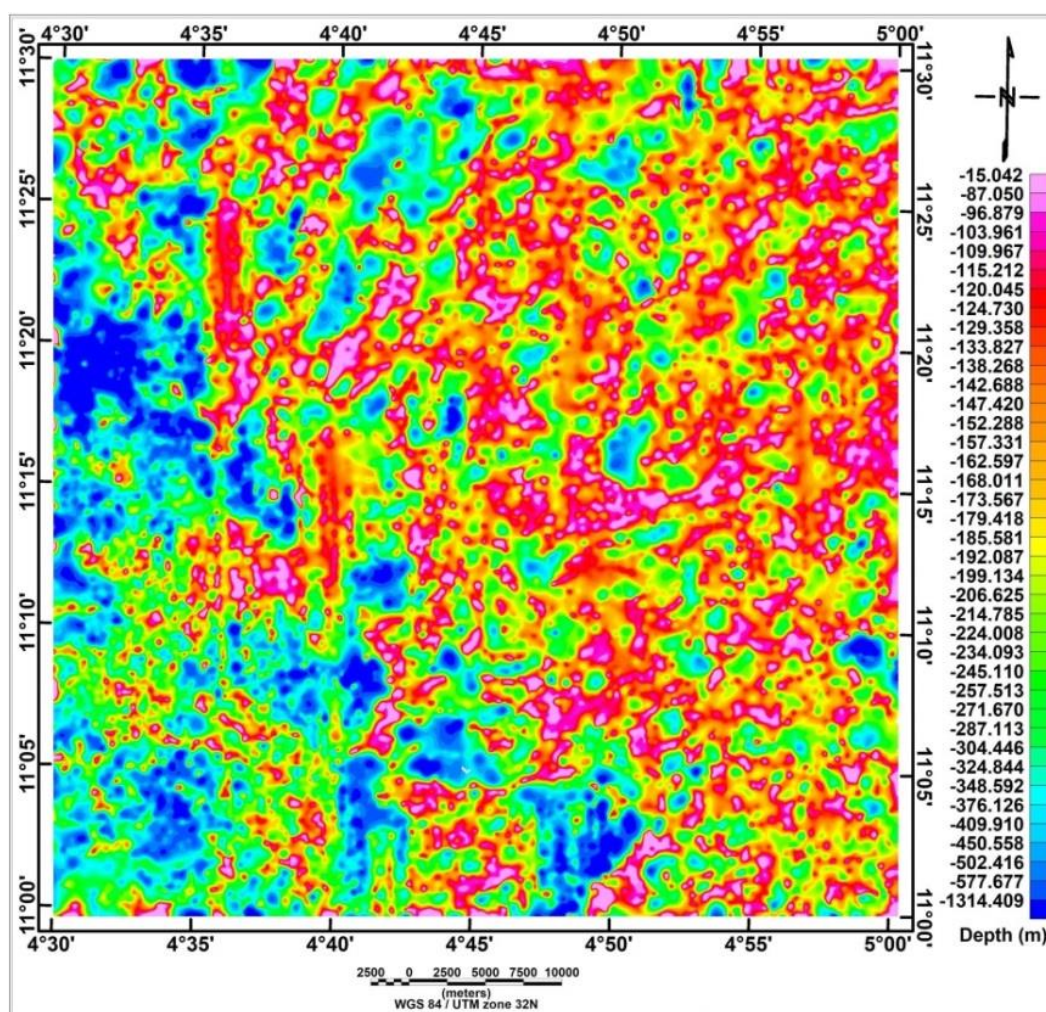


Figure 5: Source Parameter Imaging Map of the Study Area

3D Euler Deconvolution Method

The Euler solutions of depth within the study area are as displayed in fig 6: (a. Euler solution (SI= 0) for contact b. Euler solution with Structural Index (SI= 1) for structures c. Euler solution with Structural Index (SI= 2) for dykes and d. Euler solution with Structural Index (SI= 3)) for spherical bodies. In all the maps, the 3D Euler solutions were grouped into four (4). Depth < 200 m, depth between 200 - 400 m, depth between 400 - 600 m and depth >600 m, however, the most peculiar characteristics of all the Euler solutions is that solutions of shallow depth characterized the basement part of the study area while solutions with depths > 600 m characterized the sedimentary portion of the study area.

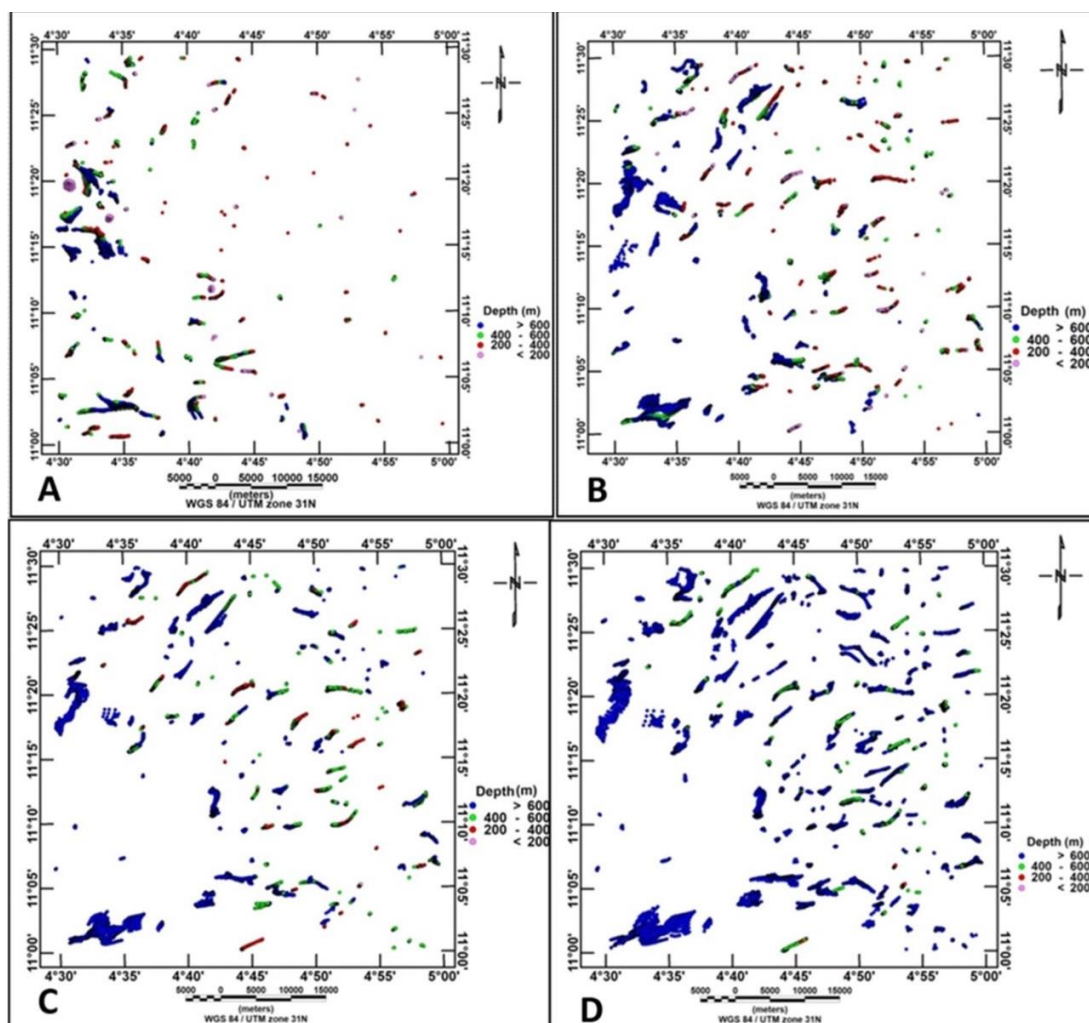


Figure 6: a. Euler solution (SI= 0) b. Euler solution with Structural Index (SI= 1) c. Euler solution with Structural Index (SI= 2) d. Euler solution with Structural Index (SI= 3)

Conclusion

Base on the analysis using the three methods of depth determination, depths obtained using the analytic signal and source parameter imaging techniques ranges from 11.457 m to 1314.409 m. These two methods yielded nearly identical results, revealing the boundary between the sedimentary basin and basement parts of the research region. The shallow sources are observed within eastern part of the study area where the overburden thickness is thin (0 - 71.968 m) and outcropping basement rocks are occupied, whereas the deep sources are observed in the southwestern part where the sedimentary cover is located and is relatively thick (1314.409 m). The 3D Euler solutions reveal shallow depths < 200 m depth and deeper source > 600 m, however, and the most peculiar characteristics of the Euler solutions is that solutions of shallow depth characterized the basement part of the study area while solutions with depths > 600 m characterized the sedimentary portion of the study area. The depths realised using the three methods was increasing towards the south-

western part of the map and decreasing towards the eastern side, where the outcropping basement rocks could be located, according to the maps.

Recommendations

- 1) In carrying out depth analysis, it is recommended that the researcher should use more than one method to give him a better understanding of the depth within the location of study.
- 2) Gravity data can be integrated with magnetic data for the study for comparison since both methods are potential methods.

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