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Full Length Research Article

DEPTH TO MAGNETIC SOURCES DETERMINATION USING SOURCE PARAMETER IMAGING (SPI) OF AEROMAGNETIC DATA OF PARTS OF CENTRAL AND NORTH-EASTERN NIGERIA: A RECONNAISSANCE TOOL FOR GEOTHERMAL EXPLORATION IN THE AREA

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ABSTRACT

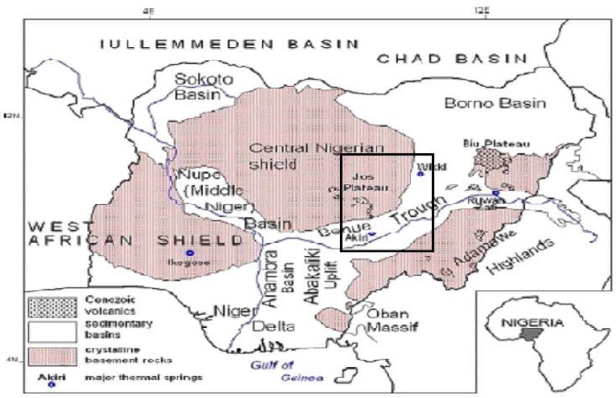
Source Parameter Imaging (SPI) of aeromagnetic data covering an area located approximately between latitude 7.5° N and 11.5° N and longitude 7.5° E and 10.5° E, which corresponds to parts of the Benue trough (lower part of the Upper Benue trough, the entire middle Benue trough, and upper part of the Lower Benue trough), lower part of the Gongola and Yola Basins, the Precambrian Basement, the Jurassic Younger Granites and two prominent hot Springs, Wiki hot spring in Bauchi state (in the north-eastern part) and Akiri hot spring in Nasarawa state (in the south-western part) of central and north-eastern Nigeria, was carried out for the purpose of estimating the depth to magnetic basement of the area. The estimated depths to magnetic sources from Source parameter imaging (SPI), range from 0.12 to 12.26 km. The highest depth can be found at the south-western part of the study area. The depth to magnetic basement is shallower mainly in the north and extreme north-eastern parts of the study area with magnetic high flanking areas of magnetic low. The above characteristics of these areas and the location of warm springs at the north-eastern and south-western parts of the study area (Wikki and Akiri hot springs respectively). Which suggests the occurrence of tectonic activities in the area, hence is an indication that, there might probably be good sources for geothermal and thereby recommended for both geothermal exploration and exploitation.

Keywords: Aeromagnetic data; Polynomial fitting; Source Parameter Imaging (SPI); Northwest-Southeast (NW-SE); Northeast-Southwest (NE-SW)

INTRODUCTION

Nigeria is currently facing incessant problem of epileptic power supply, which has affected her productivity hence, her inability as a Nation to compete socially, politically, economical, and technologically with other nations of the world. Nigeria over dependence on oil and natural gas has constituted a hindrance towards the harnessing of other sources of power that can contribute immensely to the economic growth of the nation. In other to consistently generate electricity, other sources of power that are widely referred to as renewable energy emerging in the wake of climate change and the depletion of the ozone layer should be explored (Sedara and Joshua, 2013; Olusola, 2014; NERC, 2014; World Energy Council, 2014; Ikechukwu et al., 2015).The surface manifestation of geothermal energy (i.e. Hot Springs) in the study area, is a clear indication that there exist geothermal resources, that could be harness by electricity generation and distribution companies in Nigeria. This is the main thrust of this study. Since magnetic data are related to changes in magnetic susceptibilities and depths of their sources, these data can be used to determine the locations and the depths of the magnetic bodies that have been caused by them. Different methods, based on the use of the magnetic field derivatives, have been developed to determine magnetic source parameters such as locations of boundaries and depths (Salem et al., 2008).

Researchers (Salem et al., 2008; Al-Badani and Al-Wathaf 2018) used source parameter imaging (SPI) to determine the depth to basement surface. The Source Parameter Imaging (SPI) of aeromagnetic fields over the area would differentiate and characterise regions of deep magnetic Basement (sources) from those of shallow magnetic basement and also to determine the depths to the magnetic sources. This study area is bounded by latitudes 7.50'N to 11.50'N and longitudes 7.50'E to 10.50'E located within the central and northeast Nigeria (Fig.1. and Fig. 2a-b). It is approximately 145,200 km^2 and was covered by 48 aeromagnetic maps. The study area is made up of the cretaceous Benue trough, Precambrian basement Complex, Sedimentary Basins (Gongola and Yola Basins), Jurassic younger Granites, and tertiary – recent sediments of the central and north-eastern Nigeria (Fig.2). Several related works such as Nur et al., 1999; Eletta and Udensi 2012; Ikumbur et al., 2013; Igwesi and Umego 2013; Bello et al., 2017; Mohammed et al., 2019; Abdullahi et al., 2019) have been done in the study area.



Study Area
Surface Geothermal manifestation - Hot springs.

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Fig.1: Geological setting and location of areas with major geothermal manifestation (Hot springs) in Nigeria (After Kurowska and Schoeneich, 2010)

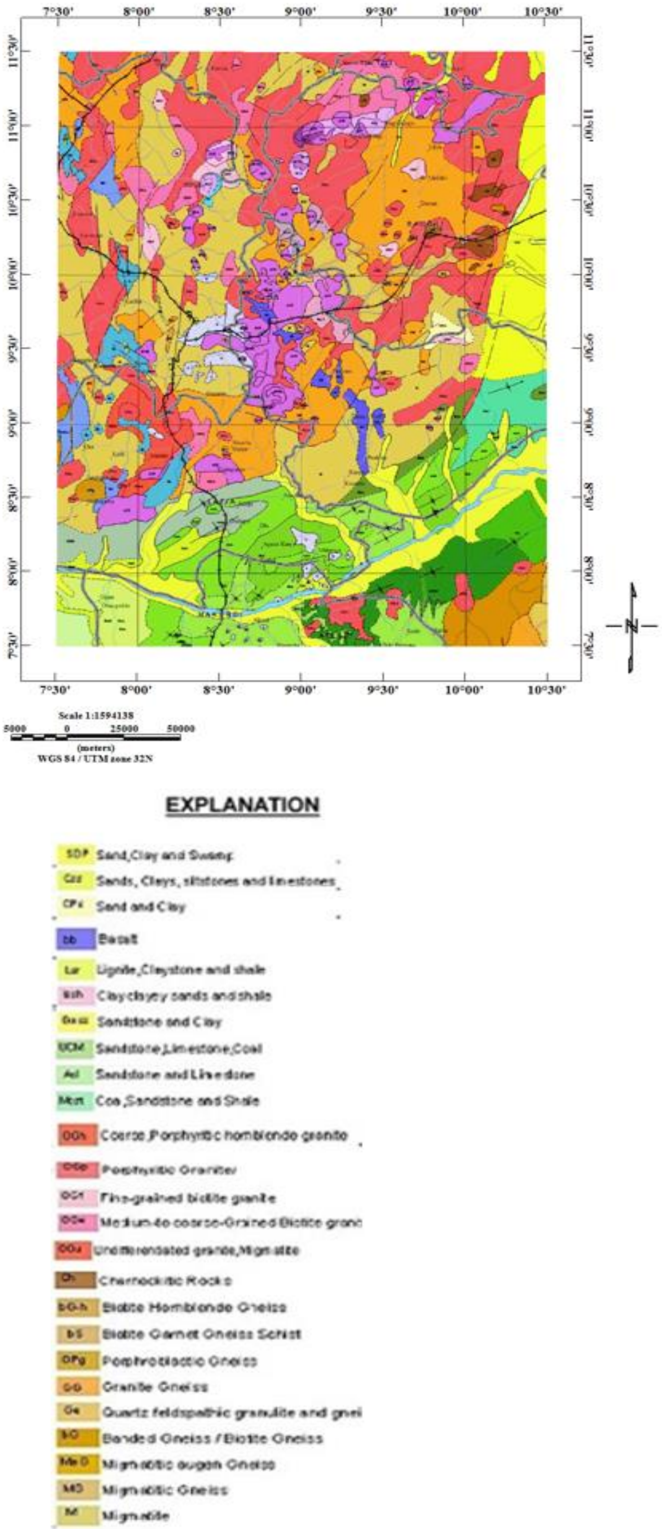

Fig.2: Geological Map of the study area (adapted after NGSA, 2010)

MATERIALS AND METHODS

The high-resolution aeromagnetic dataset used for this study was obtained from the Nigerian Geological Survey Agency as a part of the nation-wide aeromagnetic survey between 2005 and 2010. The survey was flown in drape mode using real time global positioning system at a sensor mean terrain clearance of 80-100m. Traverse and Tie line spacing were 500m and 2000m respectively in NW-SE and NE-SW directions and the data were recorded at a sampling interval of 100m (NGSA, 2010) and stored in grid form. The study area is covered by forty-eight aeromagnetic maps of total-field intensity in ½º by ½º sheets. These are numbers 102 - 107, 124 - 129, 145 - 150, 166 - 171, 187 -192, 208 - 213, 229 – 234 and 249 – 254 on a scale of 1:100000. The data were initially pre-processed by Fugro Airborne Survey and Consultant teams, pre-processing operation included micro levelling, removal of cultural effects as well as filtering for noise contents. The pre-processed data were quality controlled for isolated spikes and other spurious data which bear no correlation with geology. Butterworth filtering processing was applied to remove any possible cultural noise and other outrageous noise in order to increase the signal to noise ratio while minimizing other noise energies in the data. Total magnetic field intensity maps of the area comprising of the sheets (Fig. 3) were plotted using Oasis Montaj software (version 8.4). The composite colour map (Fig. 3) effectively displayed both long wavelength and short wavelength features. From (Fig.3), the total magnetic field intensity ranges from 32865 to 33156nT. The magnetic relief of 291nT can be attributed to the differences in magnetic mineral content between various lithology, and to the variation in depth to magnetic rocks (Bird, 1997). The residual magnetic map of the study area Fig.4, was computed after applying the trend removal function from the total magnetic field intensity composite grid and subtracting the resulting regional magnetic field intensity from it, using grid mathematics. The residual field intensity ranges from 160.35nT to 126.35nT. Comparing the geology (Fig.2) and the magnetic field intensity maps, there is sharp correlation between the geologic and total magnetic field intensity and territorial boundaries. Most of the anomalies trend NE-SW, some trend NW-SE and few trend E-W. Also, between latitude 9^0.30' to 10^0.30' N and 8^0.30' to 9^0.30' E, very high magnetic field intensity was recorded, indicating aa uplift or an intrusion trending NW-NE. It was observed that the trend pattern of the regional field is NE-SW. The direction of the magnetic fields are in conformity with the suspected structures arising from the Atlantic Ocean. Most of the structures on the residual maps are in the same direction with the total field, which shows the authenticity of the residual field.

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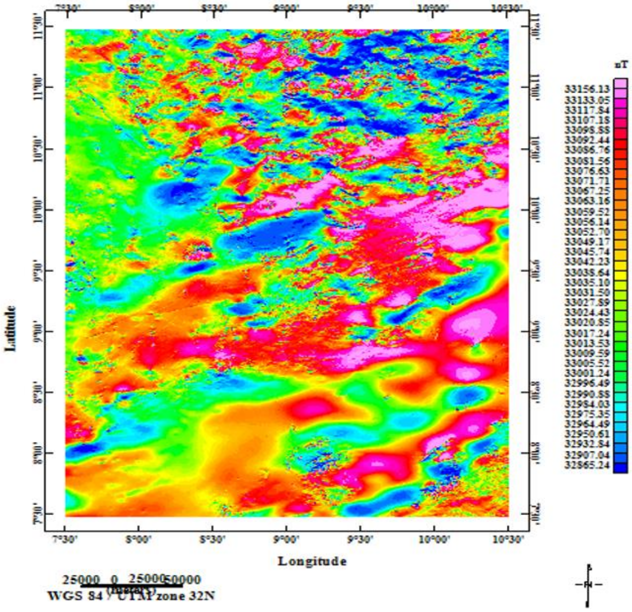

Fig.3: Total magnetic field intensity map of the study area.

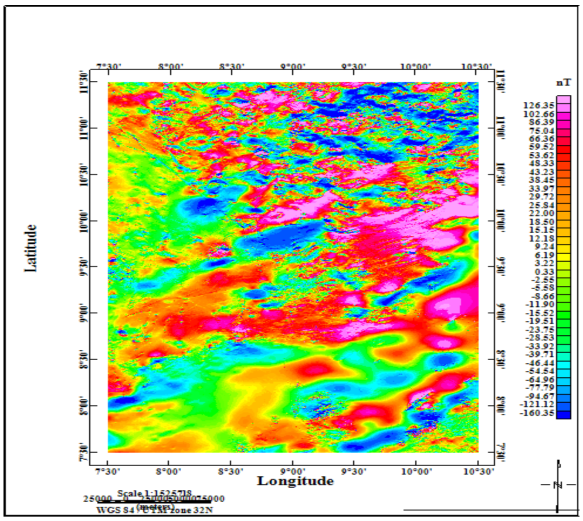

Fig.4: Residual magnetic field intensity map of the study area

Source Parameter Imaging (SPI)

SPI is a technique based on the extension of complex analytic signal (AS) to estimate magnetic depths; it is also known as local wavenumber. The original SPI method (Thurston and Smith 1997) works for two models: a 2-D sloping contact or a 2-D dipping thin sheet. For the magnetic field T, the local wavenumber is given by:

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

For the dipping contact, the maxima of k are located directly over the isolated contact edges and are independent of the magnetic inclination, declination, dip, strike and any remnant magnetization. The depth is estimated at the source edge from the reciprocal of the local wave number.

$$Depth_{(x=0)} = 1/\, k_{max} \quad (2)$$

where K_{max} is the peak value of the local of number K over the step source (Al-Badani and Al-Wathaf 2018).

The Source Parameter Imaging (SPI) function is a quick, easy, and powerful method for calculating the depth of magnetic sources and its accuracy has been shown to be +/- 20% in tests on real data sets with drill hole control (Salako 2014; Al-Badani and Al-Wathaf 2018). Another advantage of this method is that the interference of anomaly features is reducible, since the method uses the second-order derivatives. The SPI computes source parameters from gridded magnetic data. Solution grids show the edge locations, depths, dips, and susceptibility contrasts. The estimation of the depth is independent of the magnetic inclination, declination, dip, strike and any remanent magnetization (Thurston and Smith 1997). In practice, the method is used on gridded data by first estimating the direction at each grid point. The vertical gradient is computed in the frequency domain, and the horizontal derivatives are computed in the direction perpendicular to the strike using the least-squares method (Al-Badani and Al-Wathaf 2018). The depth to magnetic source was determined through several mathematical processing from various grids using Oasis Montaj software (version 8.4). The pre-processed grids from the residual grid (Fig. 4), as input grid are dx, dy and dz. These output grids were later served as input grids for SPI processing. First order derivative was adhered to, as the method (SPI) is much more sensitive to noise at higher derivative order. Therefore, careful filtering of data was ensured so as to have good estimates of the local wave number and hence the depth. Figure 5 is the depth estimates obtained from the source parameter imaging (SPI) and Fig. 6, Source parameter image (SPI) solution plot superimposed on the residual magnetic field intensity map of the study area.

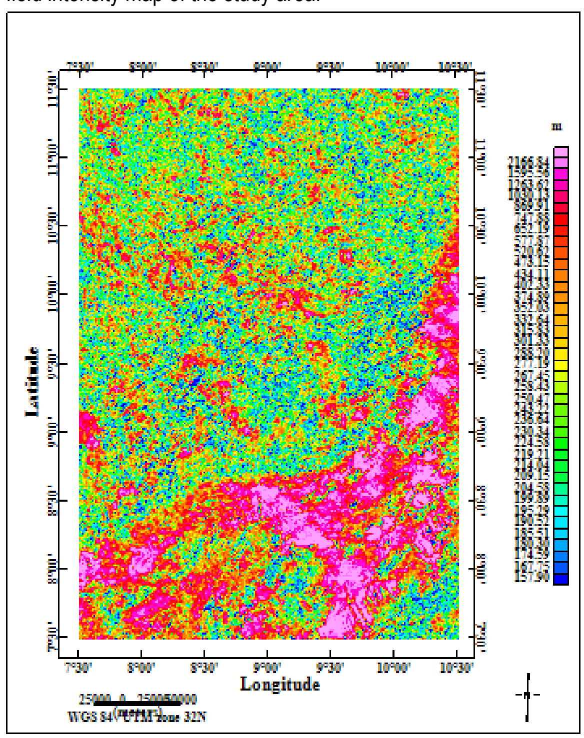

Fig. 5: Source parameter image (SPI) map of the study area

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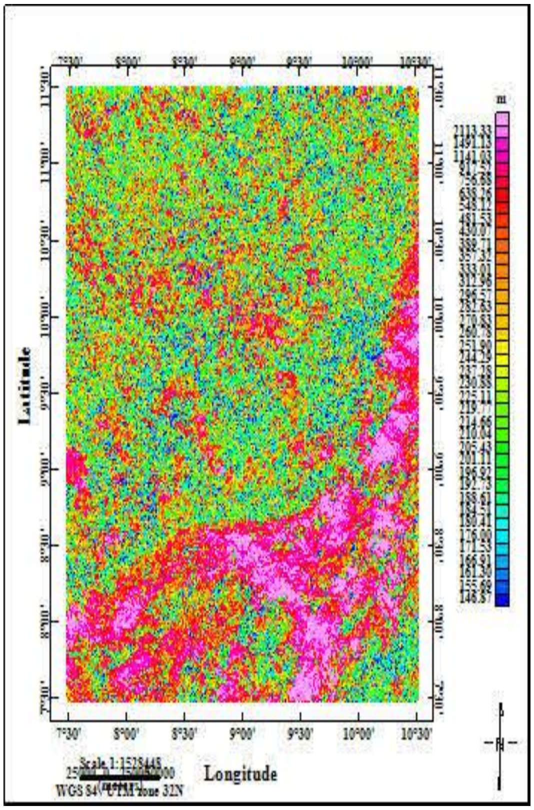

Fig. 6: Source parameter image (SPI) solution plot superimposed on the residual magnetic field intensity map of the study area.

RESULTS AND DISCUSSION

The Figure (Figure 5) shows the depth to magnetic sources range from 119.1 to 12260.7 m. The source parameter map corresponds greatly with the residual magnetic field intensity map (Fig.6). The highest depth can be found at the south-western part of the study area. However, relatively higher depth scattered around northern and north central parts of the study area The result from SPI agrees to some extent with the result from spectral depth determination Salako and Udensi (2013). The shallowest region however agrees both in location and values. Results from both depth estimate methods agreed largely with other published works in the study area. Nur, Onuoha and Ofoegbu (1994) obtained 1.6km to 5km for deeper source around middle Benue, while 60m to 1.2km was obtained for shallow magnetic source; Nwogbo (1997) got 2km to 2.62km for deeper source and 70m to 0.63km for shallow source from spectral analysis of upper Benue trough; Nur et al., (1999) stated that, the deeper magnetic sources were at depth of up to 33.28 km, representing the sedimentary cover in the study area and the highest depth to the shallower magnetic source model is 8.30km and represents intrusive/extrusive bodies within the trough Basin; Nur (2000) obtained depth range of 625m to 2.219km for deeper source and an average of 414m for shallow source at upper Benue trough. Udensi and Osazuwa (2003) obtained a maximum depth of 3.39km at Nupe; Eetta and Udensi (2012), obtained a depth range of 2-8.4km; Ikumbur et al., (2013), obtained a depth range of 2.81-3.24km; Igwesi and Umego (2013), obtained a depth of 3.03km; Bello et al., (2017), obtained a depth of 5km; Mohammed et al., (2019), obtained a depth range of 12.43-33.91km; Abdullahi et al., obtained a depth range of (2019),1-9km.

Conclusion

The estimated depths to magnetic sources from Source parameter imaging (SPI), range from 0.12 to 12.26 km. The highest depth can be found at the south-western part of the study area. However, relatively higher depth scattered around northern and north central parts of the study area. The depth to magnetic basement is shallower mainly in the north and extreme north-eastern parts of the study area with magnetic high flanking areas of magnetic low. However, some parts of the south are dotted by shallower depths. The above characteristics of these areas and the location of warm springs at the north-eastern and south-western parts of the study area (Wikki and Akiri hot springs respectively), which according to Rowland and Nur (2018), suggests the occurrence of tectonic activities could be an indication that, there might probably be good sources for geothermal and thereby recommended for further geothermal exploration and exploitation using other imaging techniques such as seismic and gravity.

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