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# EVALUATION OF DEPTH TO BASEMENT, HEAT FLOW, AND LEAD-ZINC MINERALIZATION FROM ANALYSIS OF AEROMAGNETIC DATA IN SOME PARTS OF SOUTHERN BENUE TROUGH

B. U. Ukwuteyinor., C. C. Ezeh
Department of Geology and Mining, Enugu State University of Science and Technology,
Email: benteyinor@gmail.com, benukwuteyinor@yahoo.com

***Abstract***
*The techniques of aeromagnetic data analysis were employed to elucidate depth to magnetic basement sources, lead-zinc (pb-zn) mineralisation and heat flow in parts of Southern Benue Trough. The study area covers an area extent of about 18,150 sq. Km, latitude 05 $^0$ 30'N - 06 $^0$ 30'N and longitude 007 $^0$ 30'E - 009 $^0$ 00'E. The digital aeromagnetic data consisting of Total Magnetic Intensity with geospatial attributes covering six (6) sheets 302 (Nkalagu), 303 (Abakaliki), 304 (Dangha), 313 (Afikpo), 314 (Ugep) and 315 (Ikom) were used in this study. Several magnetic digital filtering methods such as reduce to pole, low/high pass, etc were applied on the data before analysis for lineaments, mineralisation, and depth to magnetic sources. Zones of broad magnetic anomalies were found in the north eastern and south eastern part of the study area like Otam-Izekwe, Enyigba, Uburu, Abakaliki, Ndieze Izzi, Isiagu, Obubra, Oturekpe, Mkpani, Idomi, Enona, Ugep, etc. Depth estimates to the magnetic basement sources from spectral analysis range from 0.65km to 1.155 km, while depth estimate from source parameter imaging (SPI) stretches from 0.679km to 7.723km. The north western part of the study area is the deepest. Pb-zn mineralization within the study area is found to be structurally controlled trending in NE-SW and NW – SE directions. The heat flow values range from 0.65 – 1.95Wm$^{-2}$, pb-zn mineralization is within 0.9 – 1.4Wm$^{-2}$ and Curie point depth range from 0.75km to 2.1km.*

**Keywords:** Depth to basement, Heat flow, Lead-Zinc, Mineralization, Aeromagnetic data
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## 1. Introduction

Nigeria's peaceful co-existence is presently threatened by the agitation for resource control in most regions of the country. This is due to the countries over dependence on monocultural resources – Hydrocarbon which unfortunately comes from a particular region of the country. The nation's current petroleum reserve asset (proven) put at 38 billion barrels of oil and about 190 trillion standard cubic feet of gas derives largely from the Niger Delta onshore/offshore, is presently faced with multiple and diverse problems (Obaje et al, 2011). Thus, there is need to reposition the solid mineral sector of the economy which used to be the mainstay national income earner, by acquiring the necessary geoscientific information to identify and delineate available economic solid mineral deposits.

The aeromagnetic method was adopted in the determination of depth to basement sources, lead-zinc mineralization and heat flow in the study area. It has very outstanding attributes compared to other geophysical prospecting techniques because of rapid rate of coverage at a relatively low cost per unit area captured. The method is indirect and basically of reconnaissance value in mineral resources prospecting to detect trend, depth and approximate topography of the basement wide, location, outline and rough estimate of the depth to intra-sediment structures such as fault, fold and other tectonic features. The method is also widely used in location of the geometric configuration such as shapes, size and estimation of ore deposits which causes anomalies, such ore deposits are magnetic eg ilmenite, pyrrhotite, ore-bearing sulphide deposits and placer deposits like gold associated with magnetic concentrates (Walsh, 1989).
Current mining activities and previous studies in the Southern Benue Trough reveal that lead-zinc and barites resources abound in the study area. Chalcopyrite occurs as a minor sulfide. The commonest hydrothermal gangue minerals are quartz and siderite. Most of the siderite has been dissolved and re-crystallized as hematite (Ogundipe 1987). Farrington (1952) recorded that the first production of the lead-zinc ore from the mine was in 1925 as systematic mining started shortly before the world war (July 1914 – November 1918). But mining ceased at the

onset of the civil war (1966). Nwachukwu (1972), Orajaka (1965), Olade (1975, 1976) and Farrington (1952) noted that mineralization is hydrothermal and epigenetic in origin which formed at mesothermal conditions. Although mining of the lead-zinc ores commenced in all districts as early as 1925, the southern Benue Trough deposits have been relatively less studied. Several related work did in the past include Igwesi and Umego (2013), Abdullahi et al (2019), Bello et al (2017), Onuoha and Ofoegbu (1991), Nwogbo (1997) among others. This study is aimed at determining the mineralization in the southern part, depth to basement sources and the heat flow so as to guide prospective investors. The study**,** therefore apply modern geophysical software on recent magnetic data, utilizing modern techniques as well as ground truthing on some magnetic anomalies to reconcile anomalies on magnetic maps with occurrences on the ground.

## 2. Geologic setting of the study area

The study area (fig. 1) is located within Southern Benue Trough. According to King (1950), Farrington (1952), Nwachukwu (1972), Murat (1972) the Benue Trough originated as a failed arm at the time of the opening of the South Atlantic Ocean during the separation of the African plate and the South American plate. Benue Trough is defined as an intercontinental cretaceous basin about 1000 km in length stretching in NE-SW direction and resting unconformably upon the Precambrian basement. Based on the trough corresponding geological and geomorphologic partition, it is subdivided into the upper, middle and lower region. The lower which is the southern Benue Trough, is the southwestern part of the Benue depression, Nwajide (2013). It comprises of the Abakaliki Anticlinorium, Afikpo Synclinorium to the east and Anambra Basin to the west. The first marine transgressive phase in the middle to late Albian resulted in the deposition of the Asu River Group sediment. Its lithostratigrahic pile includes sandstone, siltstone, shale and limestone occurrences, Reyment (1965). The occurrence of lead-zinc deposit in SE Nigeria is dominantly restricted to the Albian sediments, Nwachukwu (1972). Wright (1968) noted that the lodes were developed at the end of Santonian folding.

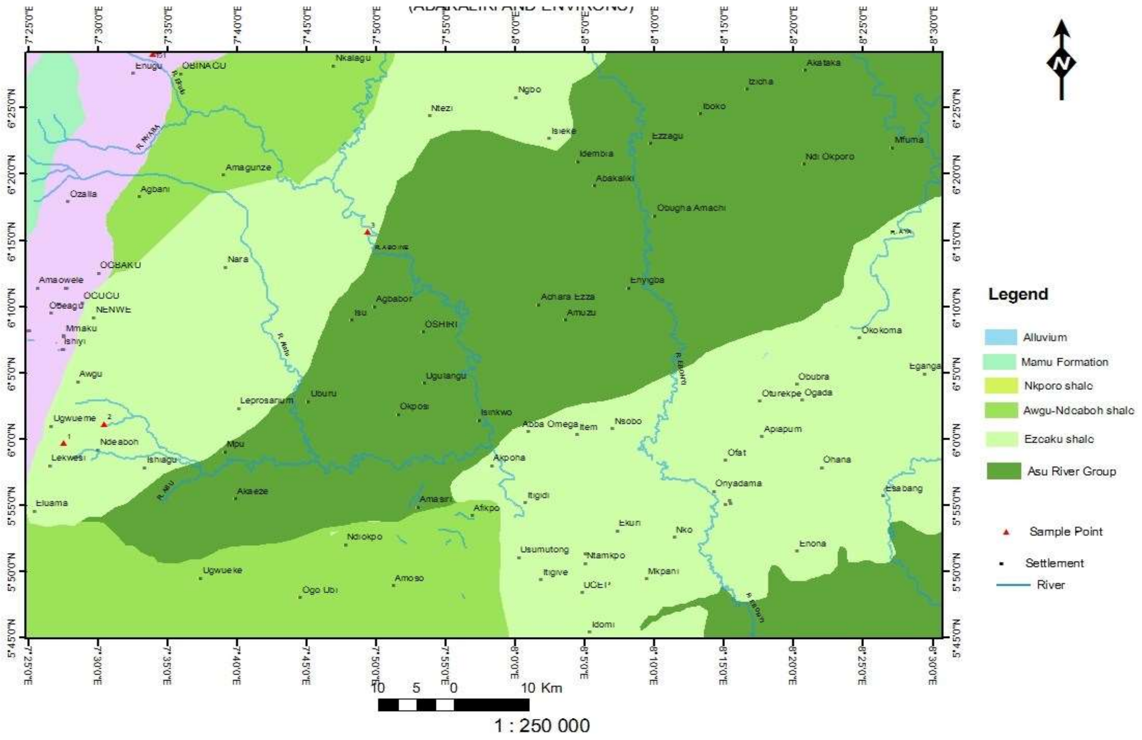

Fig. 1: Geological map of the study area. (Source: modified after NGSA, 2006)

## 3. Data description and methods

The digital aeromagnetic data consisting of Total Magnetic Intensity (TMI) with geospatial attributes covering six (6) sheets 302 (Nkalagu), 303 (Abakaliki), 304 (Dangha), 313 (Afikpo), 314 (Ugep) and 315 (Ikom) used in this study, were obtained from the Nigerian Geological Survey Agency on a scale of 1:100 000. The data was acquired in 2009 along a series of NW – SE with a flight line spacing of 500m and tie line spacing of 5 km. The flight line direction is in the direction of 135° azimuth and the tie line direction is in 45° azimuths. The flying altitude was 80m above the terrain. The average magnetic inclination and declination across the survey was 9.75° and 1.30°

respectively and the projection is WGS 1984. The geomagnetic gradient was removed from the data using the International Geomagnetic Reference Field formula (IGRF) of 2008.

The digital data was windowed from the National Grid Data base delivered in ASCII file in Geosoft Grid File format (.grd). The TMI data was further digitized in ESRI ArcGIS software for onward processing and interpretation with WingLink software and MS Excel. The data was later converted to Microsoft Excel format for easy use with other applications. The new high- resolution airborne survey carried out in Nigeria by Fugro airborne services in 2009 surveys for the Nigerian Geological Survey Agency is of higher quality than that of 1970s. The old aeromagnetic data in Nigeria in the 1970s is of lower resolution being flown at a flight line spacing of 2km, average terrain clearance of 150m, and a nominal tie line spacing of 20km and have become of limited use. Filtering was done of separate signals of different wavelength to isolate and hence enhance any anomalous feature with a certain wavelength. Near surface or shallow anomalous sources usually produce relatively short wavelengths; these are eliminated to allow a pass of longer wavelength disturbances of lower wave numbers.

Reduction to pole (RTP) is a mathematical operation which entails removing the dependence of magnetic data on the magnetic inclination i.e. converting data which were recorded in the inclined Earth's magnetic field to what they would have been if the magnetic field had been vertical. This method simplified the interpretation because for sub-vertical prisms or sub-vertical contacts (including faults), it transforms their asymmetric responses to simpler symmetric and asymmetric forms. The RTP was performed on the digitized aeromagnetic data of the study area via fast Fourier filtering programs in order to remove the dipolar nature of the magnetic field. Baranov (1957) derived the following equations for reduction to pole;

$$g' = -\mu T\,(O) - \frac{1}{2\pi}\iint T\,(\rho,\omega)\omega_3\,(\omega)\,\frac{d\rho}{\rho}\,d\omega \qquad (1)$$

Where following Baranov's notation;

$\omega_3\,(\omega) = 2\sum_{K=1}^{\infty}(-\eta)^k \;\; k(k+\mu)\cos k\,\omega$

$g' =$ total magnetic field at point O, reduced to the pole,

$\mu$ = sin *I, I* being the inclination of the observed magnetic field,

$T\,(\rho,\omega)$= total field at the magnetic observation point (*p, w*) (polar coordinates) with reference to the calculation point at the origin where the observed field is T(0), and

$$\eta = \;(I - |\sin(I))|cos(I) \qquad (2)$$

The TMI data obtained was windowed into sixteen blocks and data smoothened by moving average method in order to estimate the depth to magnetic source using spectral analysis. A fast Fourier transform was carried out on the smoothed data from which log spectral energy and spectral frequency were obtained for each windowed portion. A plot of log spectral energy was made against spectral frequency. Slopes of lines of best fit were generated which were divided by $2\pi$ to obtain the depth to magnetic basement according to Specter and Grant, (1970).

The Source Parameter Imaging (SPI) function is a quick, fast, useful, and powerful method for calculating the depth of magnetic sources. Its accuracy has been shown to be +/- 20% in tests on real data sets with drill hole control. This accuracy is similar to that of Euler deconvolution, however SPI has the advantage of producing a more complete set of coherent solution points and it is easier to use. A stated goal of the SPI method (Thurston and Smith, 1997) is that the resulting images can be easily interpreted especially with a sound knowledge of the geology. The SPI method (Thurston and Smith, 1997) estimates the depth from the local wave number of the analytical signal.

The Curie point depth is the theoretical surface with a temperature of approximately 580$^0$C and can be considered an index of the bottom of a magnetic source, due to ferromagnetic minerals converting to paramagnetic minerals and the method used to estimate Curie point depth is based on the spectral analysis of magnetic anomaly data.

The basic 2-D spectral analysis method was described by Spector and Grant, (1970). They estimated the depth to the top of magnetized rectangular prisms ($Z_t$) from the slope of the log power spectrum. Bhattacharyya and Leu (1977) further calculated the depth to the centroid of the magnetic source bodies ($Z_0$). Okubo et al., (1985) developed the method to estimate the bottom depth of the magnetic bodies ($Z_b$) using the spectral analysis method of Spector and Grant (1970).

From the slope of the power spectrum, the upper bound and the centroid of a magnetic body can be estimated. The lower bound of the magnetic source can be derived (Okubo Y., and Matsubayashi, O., 1985; Tanaka et al., 1999) as;

$$Z_b= 2Z_o-Z_t \qquad (3)$$

Where $Z_b$ is the Curie point depth, $Z_t$ is the upper bound depth, and $Z_o$ is the bottom depth.

Since $Z_b$ is the lower bound depth of the magnetic body, it suggests that ferromagnetic minerals are converted to paramagnetic minerals due to temperature of approximately 580$^0$C. Therefore, the obtained bottom depth of the magnetic source, $Z_b$ was assumed to be the Curie point depth. In order to relate the Curie point depth ($Z_b$) to Curie point temperature ($580^0$C), the vertical direction of temperature variation and the constant thermal gradient were assumed. The geothermal gradient ($dT/dZ$) between the Earth's surface and the Curie point depth ($Z_b$) can be defined by Equation

$$dT/dZ = 580^0C/Z_b \qquad (4)$$

Where $dT/dZ$ = temperature gradient, $580^0$C is the Curie point temperature.

A relationship equally exists between heat flow on the earth and the geothermal gradient. The basic relation for conductive heat transport is the Fourier's law. In one-dimensional case under assumptions that the direction of temperature variation is vertical and temperature gradient ($dt/dz$) is constant; Fourier's law takes the form:

$$q_z = -kdT/dz \qquad (5)$$

Where $q_z$ = the heat flow, k = thermal conductivity.

Provided there are no heat sources or heat sinks between the earth's surface and the curie-point depth, the surface temperature is 0°c and $dT/dz$ is constant. The Curie temperature depends on magnetic mineralogy. Although the Curie temperature of magnetite ($Fe_3O_4$), for example, is at approximately 580°C, an increase of titanium (Ti) contents of titan magnetite ($Fe_{2x}Ti_xO_3$) causes a reduction of the Curie temperature. A Curie-point temperature of 580°c and thermal conductivity of 2.5 $Wm^{-1}$°$C^{-1}$ as average for igneous rocks is used as standard in the study.

## 4.0 Results and Discussion

The total magnetic intensity map of the study area (Fig. 2) shows that a great variation in magnetic intensity exists within the study area ranging from -0.057nT – 0.019nT. Low magnetic intensity values are prominent at the southern and the eastern flank of the study area. The aeromagnetic map of the study area is relatively subdued in a manner characteristic of sedimentary terrain. A basin is characterized by smooth contours and low magnetic contours as shown in fig. 2 below.

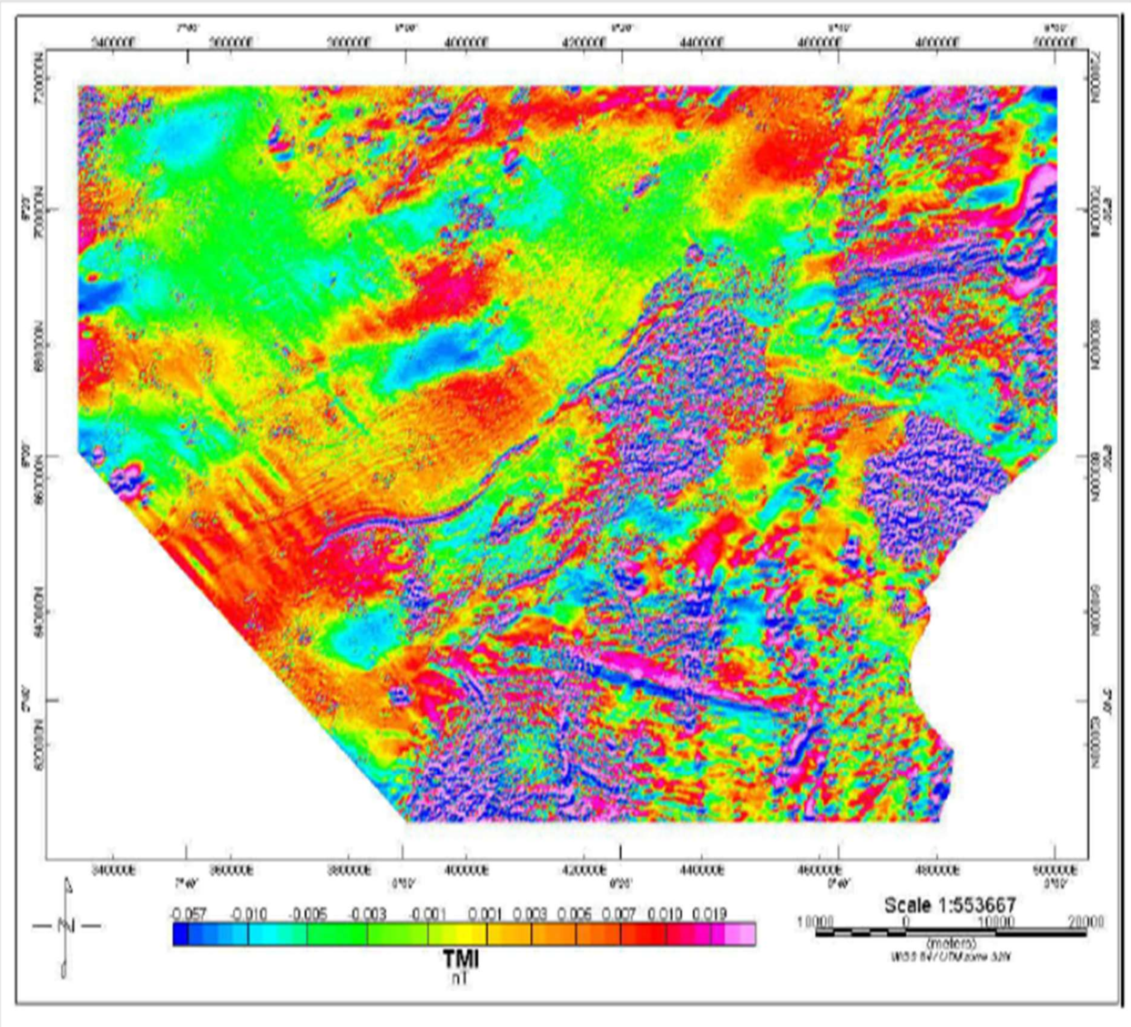

Fig. 2: Total magnetic intensity map of the study area

The residual map of the study area (Fig. 3) varies in magnetic intensity values from -0.0426nT – 0.02617nT with predominant NE - SW and NW-SE trends and steep gradients which are distributed throughout the area. The dominant long wavelength anomalies with spatial scales of several kilometers are certainly due to deep seated basement under the basin, as seen in the north western part. The maximum intensity value 0.02617nT is observed around southern and northeastern part of the study area, these areas are close to basement rocks in Cross River and Benue states.

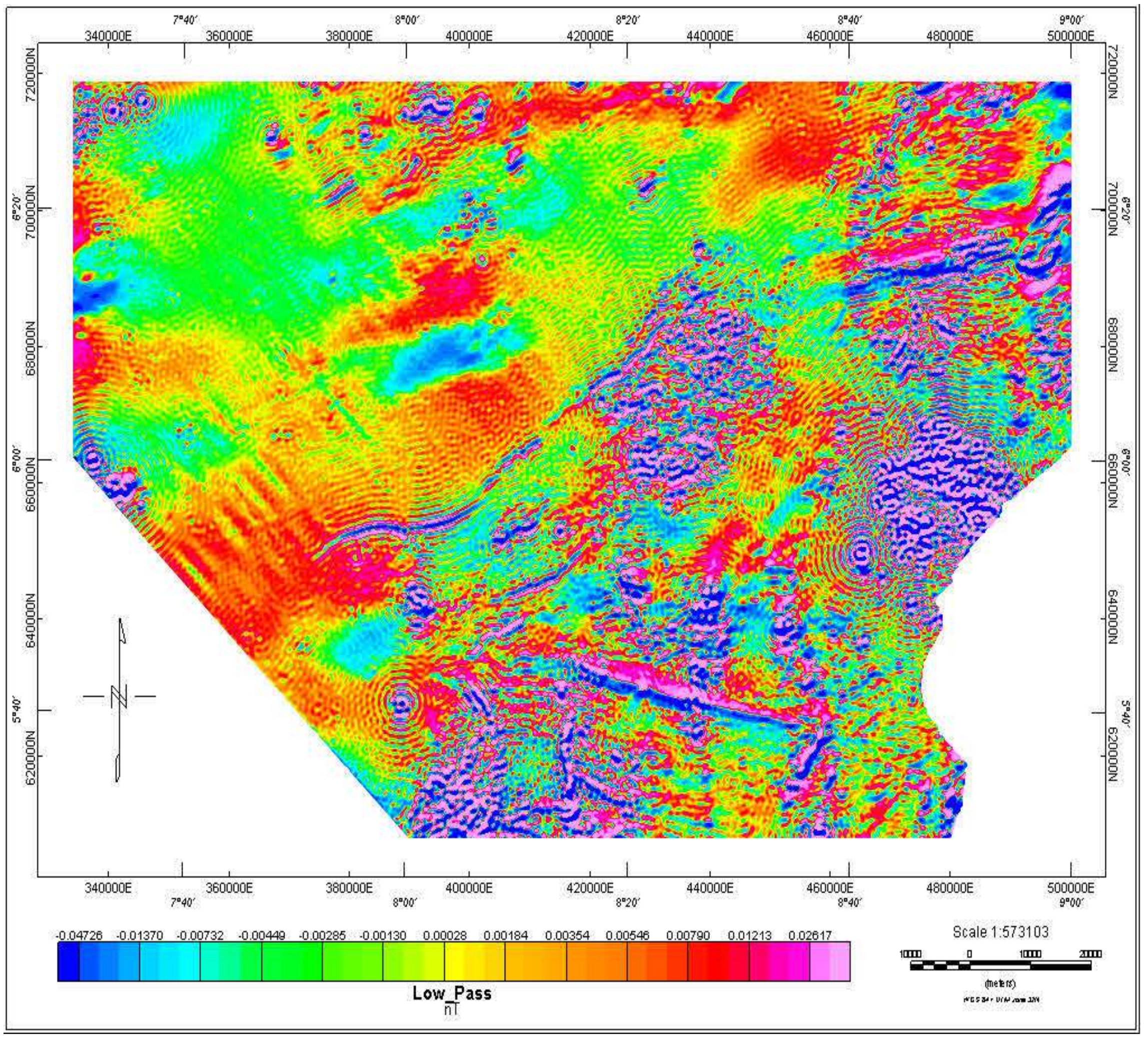

Fig. 3.: Residual map of the study area

The depth estimate methods employed in this study are spectral analysis, and source parameter imaging (SPI). The estimated depth to magnetic basement sources from spectral analysis varies from 400m to 1150m while depth estimates from SPI varies from 0.679km to 7.723km. The shallower magnetic sources in the region may be attributed to shallow intrusive materials or some near surface basement rocks, Nwogbo (1997). The deepest parts are in the northwestern part of the study area. However, relatively higher depth scattered around north eastern and north central parts of the study area. The southeastern and southwestern parts of the study area like Ohafia, Ugep, Obubra, etc are shallower. Thus, both spectral analysis and SPI agrees with the residual map. Results from both depth estimate methods agreed largely with other published works in the study area. Onuoha and Ofoegbu (1991) estimated 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; Igwesi and Umego (2013), assessed a depth of 3.03km. However, this present work is focused on Southern Benue Trough and thus, contributes to the previous works.

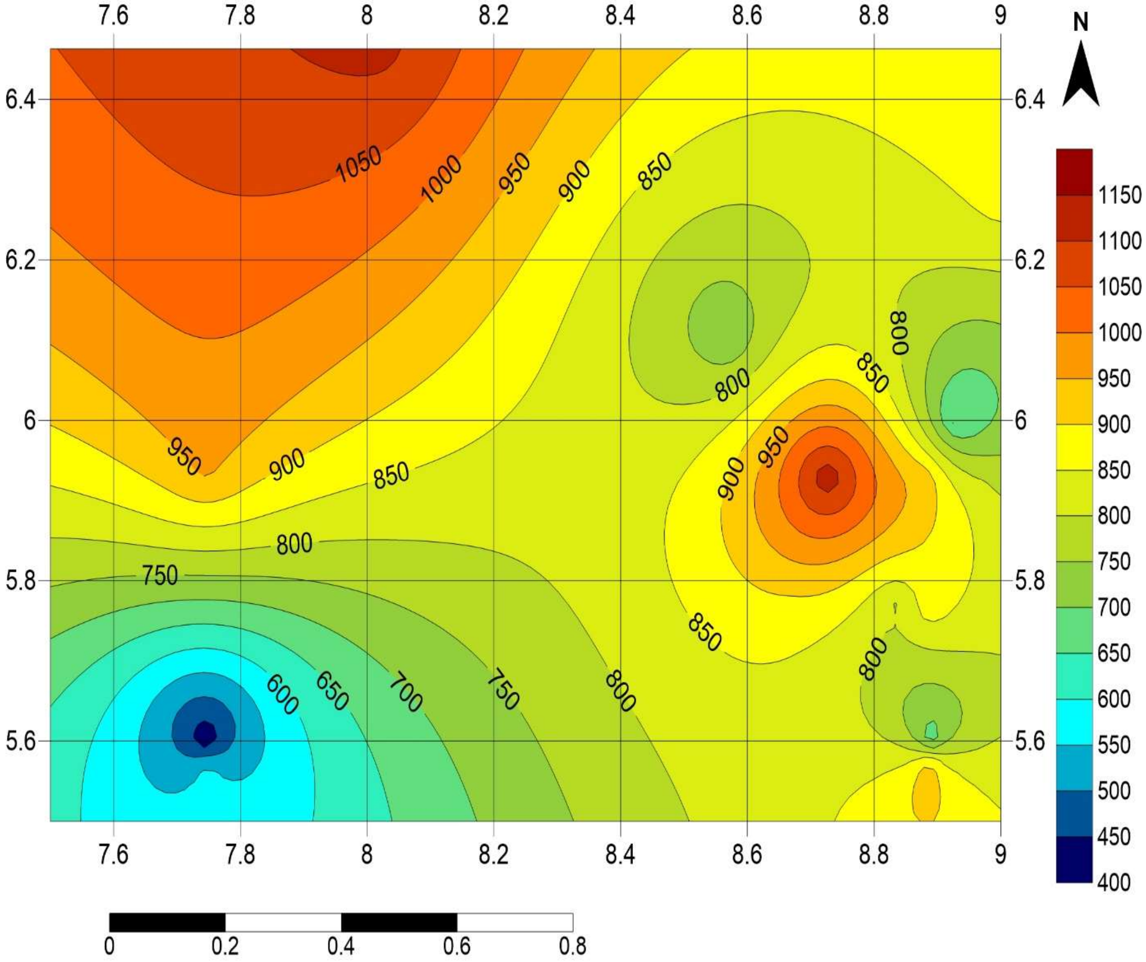

Fig. 4: Depth to deeper magnetic source from spectral analysis

In the study area, the curie depth point is highest around the north western quadrant (about 2.1km) and decreases towards the south western quadrant of the study area (0.75km) (Fig. 6)

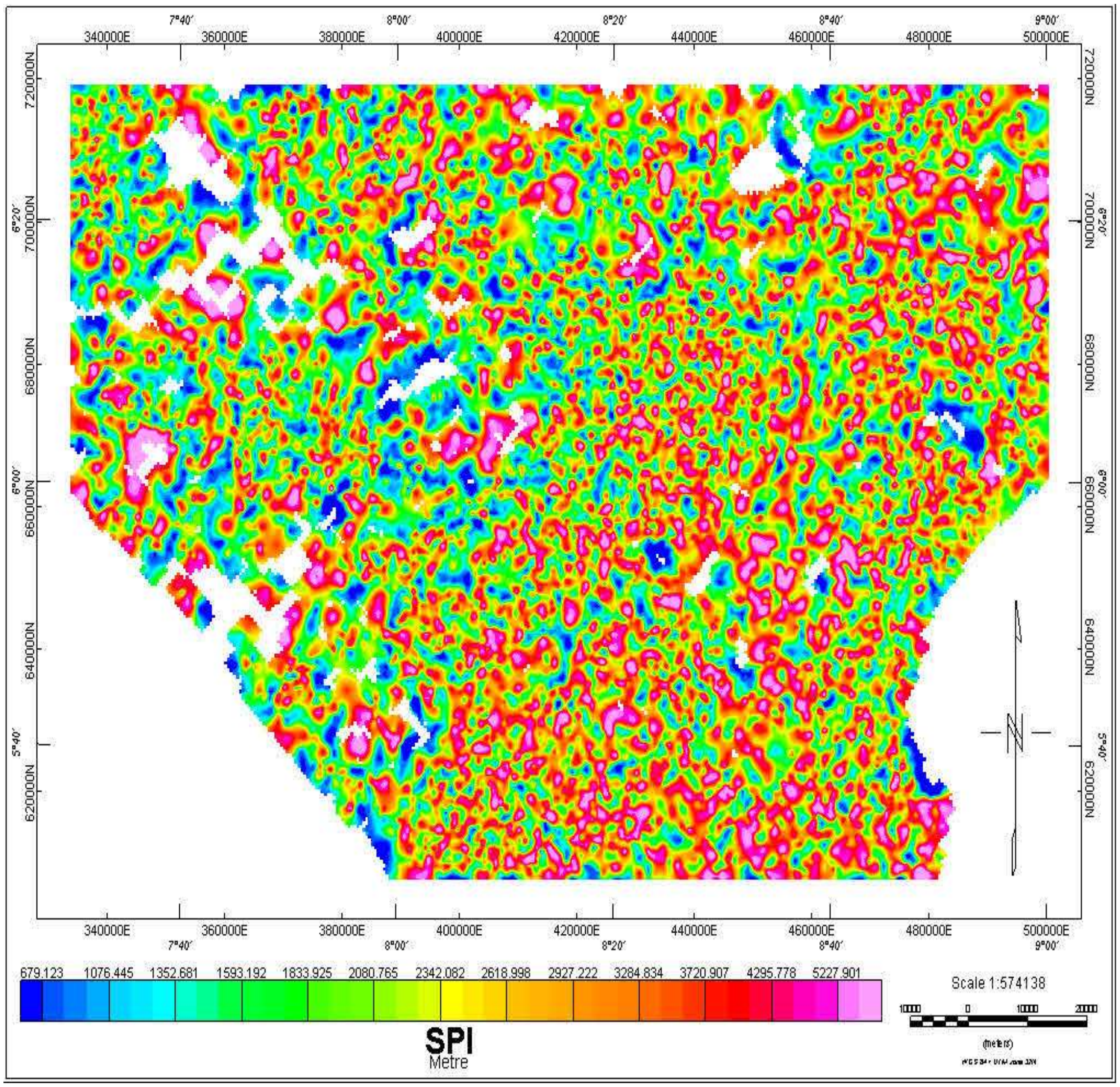

Fig. 5: Source Parameter Imaging (SPI) map of the study area

The heat flow decreases from the south western quadrant to other part of the study area. Heat flow values of 0.65 – 1.95Wm$^{-2}$ are recorded in the study area (Fig. 7). Lead-zinc mineralization are largely within heat flow range of 0.9 – 1.4 Wm$^{-2}$ .

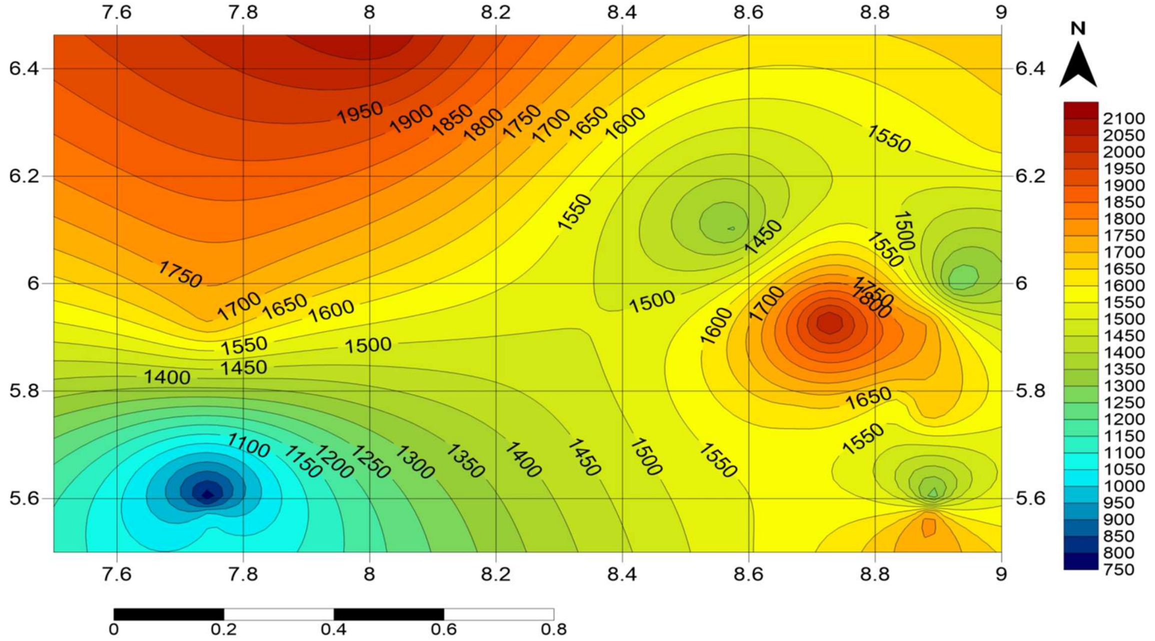

Fig. 6: Curie point depth map of the study area

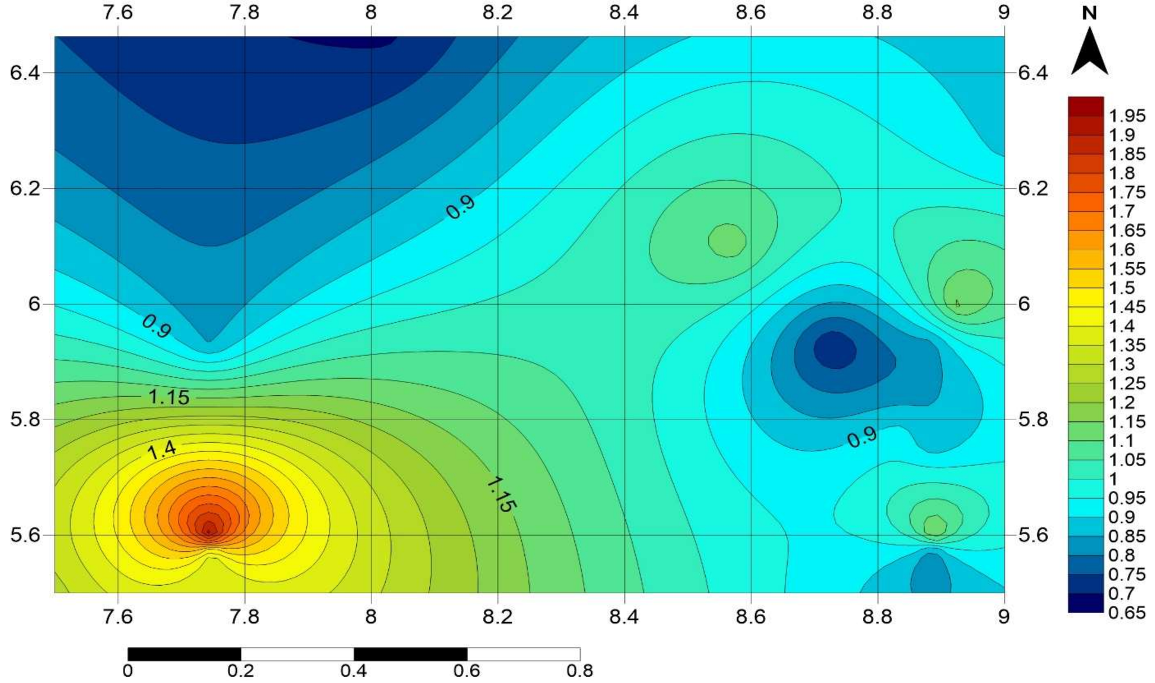

Fig. 7: Heat flow map of the study area

## 5.0 Conclusion

The depths to the basement sources were determined from spectral depth analysis and source parameter imaging. The estimated depths to magnetic sources from Source parameter imaging (SPI) stretches from 0.679km to 7.723 km. The highest depth can be found at the north 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 south and south-eastern parts of the study area. However, some parts of the north are dotted by shallower depths. Generally, basement depth (deep depth) ranges from 1.15km to 7.723km in the study area. These methods of depth determination employed showed a very good similarity of results. The deepest depth of 7.723km represents the magnetic rocks that were emplaced or intruded into the basement surface underlying the basin. It may also be due to the presence of intra-basement features such as fractures and faults. These deepest depths thus represent the depth to the deeper magnetic source. The heat flow decreases from the SW quadrant to other parts of the study area. Lead-zinc mineralization in the study area is structurally controlled, trending mainly NE-SW, NW-SE and restricted largely to albian sediments (north eastern and south eastern part of study area). Lead-zinc are found within heat flow values of about 0.9 – 1.4W/m$^{-2}$. The areas of active mining agree largely with the mineralization signatures in the aeromagnetic map.

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