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# INTERPRETATION OF HIGH RESOLUTION AEROMAGNETIC DATA FOR DELINEATING LITHOLOGICAL BOUNDARIES, STRUCTURES AND DEPTH TO THE BASEMENT PARTS OF SOUTHERN BENUE TROUGH AND ANAMBRA STATE.

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**Abstract:**

Availability of high resolution data is adequate in mapping subtler and low amplitude anomalies mapped in this study. Nine sheets of Aeromagnetic data was evaluated in order to estimate the depth to basement and to delineate lithological boundaries and structures responsible for hosting mineral resources. Depth slicing techniques were used to delineate the lithological boundaries and structures in the study area. Depth to basement estimation of the area for Standard Euler deconvolution ranges from 619.3m to 1748.9m for structural index (SI) of 0.5, for SI = 1, depth ranges between 719.8m and 1719.2m, for SI = 2, depth ranges between 416.9m and 1640.3m, for SI =3, the depth ranges from 623.0m to 1688.9m. The SPI depth result ranges from 351.1m (0.351.1km) for the shallow magnetic sources to 2207.2m (2.2072km) for the deep magnetic sources. Hydrocarbon may be recommended in some of the area since some of the area has appreciable thickness of sediments on the average. The geological structures in form of lineaments delineated serve as host to mineral deposit.

**Keywords:** Euler-Deconvolution, Benue Trough, Depth to basement, Source Parameter Imagery (SPI).

## Introduction

Nigerian Federal government initiative to diversify our income not to be over dependent on crude oil brought about engaging the services of Fugo Airborne Surveys limited to acquire high resolution data used in this research. This high resolution data is adequate in mapping subtler and low amplitude anomalies mapped in this study. Depth to basement, lithological boundaries and structures are important in our exploration efforts and the most useful pieces of information to be obtained from aeromagnetic data. The use of Airborne magnetic surveys ranges from mineral exploration (Murphy, 2007), structural mapping and rock characterization (Telford *et al.,* 1990). During the past five years, acquisition system with a precision of ± 0.01nT at a survey altitude of approximately 100m above ground or sea level have become standard with the installation of optically pumped caesium and helium vapour magnetometers, improves compensation systems to remove the magnetic effects of survey aircrafts and the use of GPS navigation, which allows flight-line positioning to ±10m or better (Gunn, 1997). Depth to basement is important in our exploration efforts and often one of the most useful pieces of information to be obtained from aeromagnetic data. Several methods have evolved in the early days of magnetic interpretation simply to estimate the depth of sources from their anomalies without reference to any specific source models (Reeves, 2005). In this study the automatic Standard Euler –Deconvolution Source parameter imagery methods are used to estimate the depth to basement of the area.

### *Geology of Southern Benue Trough*

The study area lies between latitude $6^{0}00^{1}$ - $7^{0}30^{1}$N and longitude$7^{0}30^{1}$ - $9^{0}$ $00^{1}$ E covering parts of the southern Benue trough and Anambra basin of Nigeria (Fig. 1). The separation of the African continent from the South American continent in the Aptian led to the tectonic evolution of the Benue Trough (Grant, 1971). It is a rift basin system, which trends NNE – SSW of about 800 km length and 150 km width (Olade, 1975). The Benue Trough is subdivided into the Southern portion, the Central portion and the Northern portion. There is no line that demarcates the individual portions but major localities (towns/settlements) constitute the depocentre of the individual portions (Obaje *et al.,* 1999; Burke *et al.,* 1970). The Trough contains about 5000 m of Cretaceous sediments (Adighije, 1979) which predates the Mid- Santonian compressional folded, faulted and uplifted strata in several places. Sedimentation in the Southern Benue Trough commenced with the marine Albian Asu River Group (Ojoh, 1992). The Asu River group comprises of the shales, limestones and sandstones lenses of the Abakiliki Formation in the Abakiliki area and the Mfasoming limestone in the Calabar flank (Peters and Ekwezor, 1982). Ojo (1992) also reported some pyroclastic of Aptian-early Albian ages. Awi Formation is the basal, non-calcareous, sandy conglomeratic unit of Asu River Group directly overlying the basement complex (Oban Massif) north of calabar. The marine Cenomanian – Turonian Nkalagu Formation (black shales, Limestones and siltsones) and the interfingering regressive sandstones of the Agala and Agbani Formations rest on the Asu River Group. The Mid-Santonian deformation in the Benue Trough displaced the major depositional axis westward resulting to the formation of the Anambra Basin. Post-deformational sedimentation in the Southern Benue Trough, comprises of the Anambra basin sediments. Sedimentation in the Anambra thus commenced with the Campanian-Maastrician marine and parallic sediments of the Nkporo Group consisting of the Enugu, Nkporo and Owelli Formations, overlain by the coal measures of the Mamu Formation, the fluviodeltaic sandstones of the Ajali Formation and the Maastritian-Daian parallic sediments of the Nsukka Formation, which constitutes the topmost stratigraphic unit in the Anambra Basin overlies the Ajali Formation. The Paleocene marine shales which rightly belongs to the outcropping Niger Delta stratigraphic succession (Nwajide, 2013; Mode and Odumodu, 2014). (See Figure. 1).

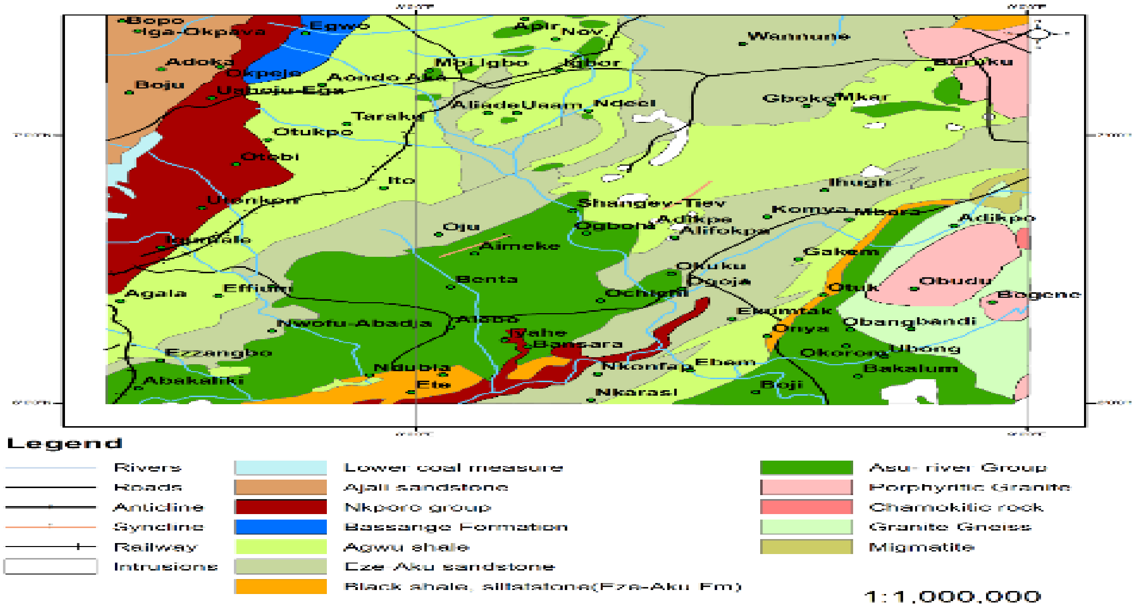

**Figure. 1: Geological map of the study area.**

## Methodology

Nine sheets of aeromagnetic data were procured from National Geological Survey Agency, Abuja. They are sheet 269, 270, 271, 288, 289, 290, 302, 303 and 304. The magnetic data recording was done with 0.1s interval. The data were acquired along a series of NW-SE flight line with a spacing of 500m. The Geomagnetic gradient was removed from the data using the international Geomagnetic Reference Field (IGRF). The total magnetic intensity (TMI) were produced in colour aggregate using Oasis maontaj software after which the horizontal (dx, dy) and vertical (dz) derivatives were computed. Magnetic survey data in the grid form were interpreted rapidly for source positions and depth using 3D standard Euler's de-convolution homogeneity relation equation of Reid et al., 1990 and source parameter imagery (SPI) or SPI™ (Thurston and Smith, 1997) techniques. Depth slicing techniques were used to delineate the lithological boundaries and structures in the area. Gridding were done using 100m cell size and bi-directional method of gridding. The bi-directional spline (usually employing some form of damping such as the akima spline) approach is usually most accurate and has fewest side effects (Marcotte *et al.*, 2005). The data is on the scale of 1: 100,000

### *Theoretical background of the semi-automated depth to basement techniques used:*

Depth to the basement, dip or other parameter may be necessary to be recorded for every anomalies recorded on every flight line (Reeves, 2005). This of course involves working with numerous thousands of anomalies. The task is carried out practically by recourse to automated (often proprietary) inversion processes. Presence of intrusive (Intrasedimentary/Intrabasement) type magnetic sources cause difficulty in quantitative interpretation of magnetic data using conventional interpretational techniques (Mahbubar and Shaikh, 2013). Depth to basement, faults in the basement surface, and the relief of the basement surface can be used to map the basin floor morphology and have direct relevance to the depositional and structural history of an area. The Standard Euler Deconvolution is a quick means of magnetic grid processing to drive depth estimates in an automatic or semiautomatic manner and trends (Reid *et al.*, 1990). It was devised by Thompson (1982) for profile data but Reid *et al.*, 1990 later developed it for 3D gridded data. The magnetic field and its gradient components are related to the anomalous source locations. It exploits Euler's inhomogeneity relation to estimate depths to the source and positions in an aeromagnetic survey grid from the maximum curvature of anomalies present (Reeves *et al.*, 1998). Euler's homogeneity relationship for magnetic data can be written in Cartesian coordinate form of the linear equation as follows (Thompson, 1982)

$$(X - X_0)\frac{\partial T}{\partial X} + (Y - Y_0)\frac{\partial T}{\partial Y}(Z - Z_0)\frac{\partial T}{\partial Z} = N(B - T)$$

………………………………………………equation 1

Where: ($X_0$, $y_0$, $z_0$) is the position of the magnetic source whose total field ($T$) is detected at ($x, y, z$,).
$B$ is the regional magnetic field.

$N$ is the structural index (SI). The degree of homogeneity expressed as a "structural index" is rate of the field's fall-off with the distance from the source. Complicated bodies which are in effect, multiples of dipoles, have 0-3 indices range. The accuracy of the method depends on appropriate SI value setting and the use of least-squares inversion to solve the equation for an optimum $x_0$, $y_0$, $z_0$ and B. To produce solutions for magnetic sources depth and positions, Reid *et al.*, 1990 automated the solution of this linear equation for gridded data.

The Euler de-convolution process is applied at each solution as well, a square window size must be specified which consists of the number of cells in the gridded dataset to use in the inversion at each selected solution location. The window is centred on each of the solution locations. All points in the window are used to solve Euler's equation for solution depth, inversely weighted by distance from the centre of the window. The window should be large enough to include each solution anomaly of interest in the total field magnetic grid, but ideally not large enough to include any adjacent anomalies.

Implementation of this method within user-friendly software packages has made its application to gridded data popular recently (Reeves, 2005). Vertical and horizontal Derivatives were used to generate the automatic standard Euler de-convolution depth to source.

***Source parameter imagery (spi) or spi™ (thurston and smith, 1997):***

In this research, the Source Parameter Imaging or SPI™ (Thurston and Smith, 1997) was use to determined depth to source. The SPI$^{TM}$ stands for Source Parameter Imaging are trademarks of Geoterrex. SPI (Thurston and Smith, 1997) is a procedure for automatic calculation of source depths from gridded magnetic data. The depth solutions are saved in a database. Magnetic inclination and declination do not affect these depth solutions. The relationship between source depth and the local wavenumber (k) of the observed field can be calculated for any point within a grid of data through the horizontal and vertical gradients used in this method. The source depth is equal to n/k at peaks in the local wave number grid, where n depends on the assumed source geometry (analogous to the Euler deconvolution's structural index) for example n is equal to 0, for a contact, n is equal to 2 for a dyke. Peak tracking algorithm is used to identify the peak wavenumber grid. This method basically assumed is that the inverse depth is defined by the peaks of the local wave number. The SPI therefore assume a step-type source model. For this model the following formula holds

$$Depth = \frac{1}{K_{MAX}} = \frac{1}{\left(\sqrt{\left(\partial Tilt/\partial x\right)^2 + \left(\partial Tilt/\partial y\right)^2}\right)_{MAX}}$$

$$Tilt = \arctan\left(\frac{\partial T/\partial Z}{\left(\partial T/\partial x\right)^2 + \left(\partial T/\partial Y\right)^2}\right) = \arctan\left(\frac{\partial T/\partial z}{HGRAD}\right)$$

……………….equation 2

Where Kmax is the peak value of the local wavenumber over the source (horizontal gradient of Tilt derivative)

T is the Total Magnetic Intensity grid

∂Tilt is the Tilt Derivative grid

∂x is the horizontal derivative in the x-direction

∂y is the horizontal derivative in the y-direction

∂z is the horizontal derivative in the z-direction (first vertical derivative)

**Results and discusion: the euler de-convolution analysis:**

The legend in Figure 2 shows different colours and their values which represent the depth to the basement in various positions on the gridded map with global coordinate. Depth to basement of the study area were calculated using the Oasis montaj software ranges between 416.9 m minimum value to 1748.9m maximum values. The negative sign in the depth implies it is below the earth surface, any area (as within the south-east area of the study area) with positive value in the depth legend bar value of the standard Euler de-convolution map (Figure 2) implies that there is a rock protrusion/intrusive above the earth level in the study area, blue colour indicating deepest to magnetic source. The study area contains a range of sources with differing geometry, thus several structural index (0.5, 1, 2, and 3) were used (Reid *et al.*, 1990). The structural index is critical to obtaining meaningful results and normal situation. Structural index of 0.5 calculates the contact solutions, structural index of 1 calculates the dyke/sill solutions, and structural index of 2 calculates a vertical pipe anomaly bodies and structural Index of 3 calculates a point dipole (Daniel, 2015).The depth ranges for different structural index are as follows: Depth ranges for SI = 0.5m, ranges from 619.3m to 1748.9m, for SI = 1, depth ranges from 1719.2m to 719.8m, for SI = 2, depth ranges from 1640.3m to 416.9m, for S.I =3, the depth ranges from 1688.9- 623.0m (see Figure 2a-2d). Results of the 3-D Standard Euler deconvolution revealed the presence of several geologic bodies which includes contacts, sills/dikes, pipes/cylinders and spheres. These geobodies are located at a depth range of 416.9m -1748.9m within the study area.

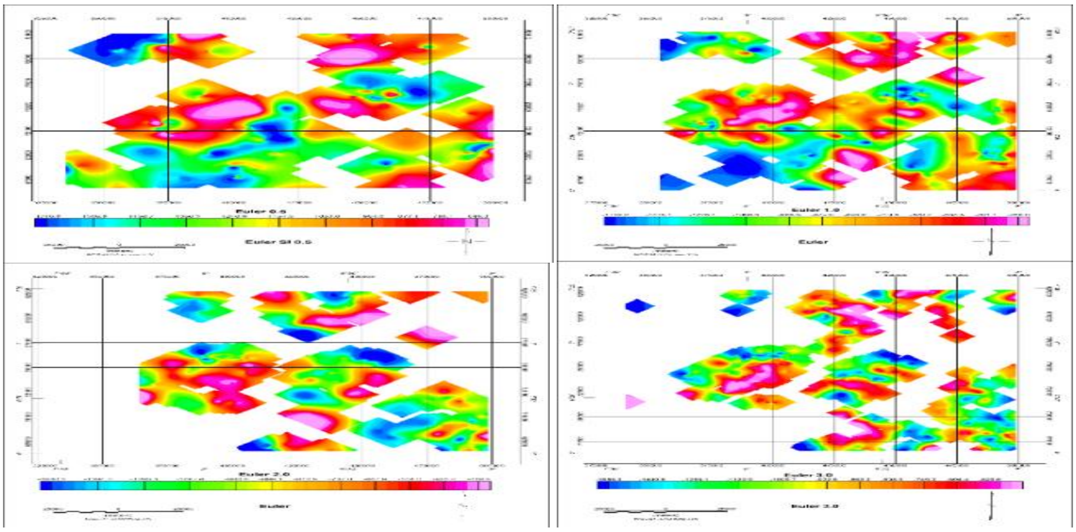

**Figure. 2: Standard Euler Deconvolution depth grid for SI= 0.5. SI=1. SI =2. and SI=3**

The depth to the magnetic by source parameter imaging (SPI) calculated is shown in a grid in figure. 3. The depth values shown in negative sign indicate that the depth is below the earth surface. The areas covered by shallow magnetic bodies are in pink coloration while the area in blue colour depicts areas covered by deep magnetic sources. The SPI depth result ranges from 351.1m (0.351.1km) for the shallow magnetic bodies to 2207.2m (2.2072km) for the deep magnetic bodies. This deepest depth estimated by SPI fairly agreed with the wright *et al.*, 1985's work that the minimum thickness of the sediment needed for the commencement of oil formation from marine organic remains would be 2300m (2.3km). So, deepest part of the study area is capable of accumulation of hydrocarbon. The Source parameter imagery ( SPI) has shown that the deepest parts of the area with depth greater than 2km is around Ankpa-Enugu-Ezike-Orukpa-axis in northwestern portion of the area, around Shangev-tiev axis in the northeastern portion and Iyahe-Basara-Nitrogom axis at the southeastern portion of the study. Shallow solutions of <1km are dominant around intrusive areas in the southern Benue Trough and around the basement area. The depth to the basement values fairly agree with the result of past researchers that have worked in Benue Trough like Igwesi and Umego (2013), Anudu et al., 2012, Adetona and Abu (2013).

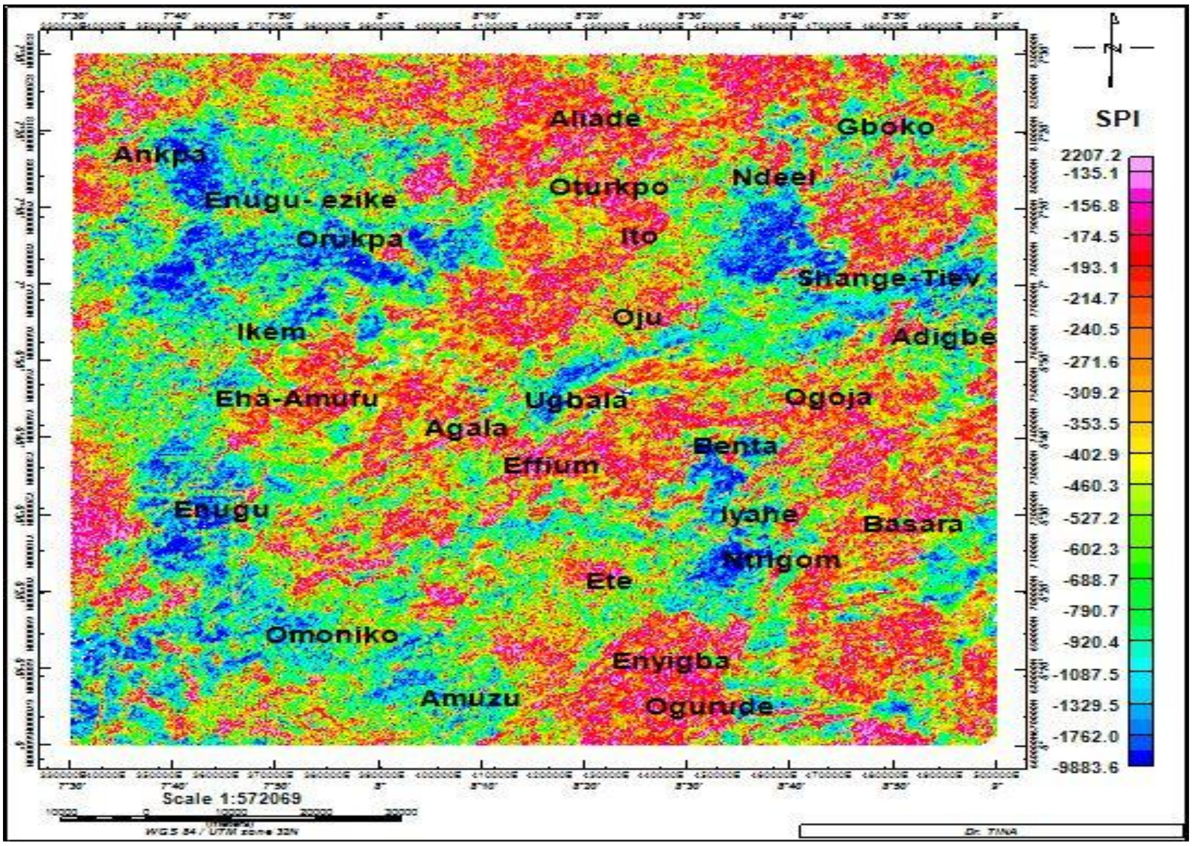

Figure.3: SPI image of the study area.

**Depth Slice 1:** The depth slice 1 grid is shown in figure 4. The grid revealed regional basement anomalies at depth greater than 8km. The grid displayed a fault system at the northeastern portion of the study area, lithologic boundaries and lineament structures (figure 4). The lineament structure at the southern portion is the contact between the Asu River sediment and the outcropping Anambra basin at that area. The lineament structures confirmed the pan Africa tectonic activity (NE-SW trend). It revealed magnetization due to intra-basement features and lithological variation.

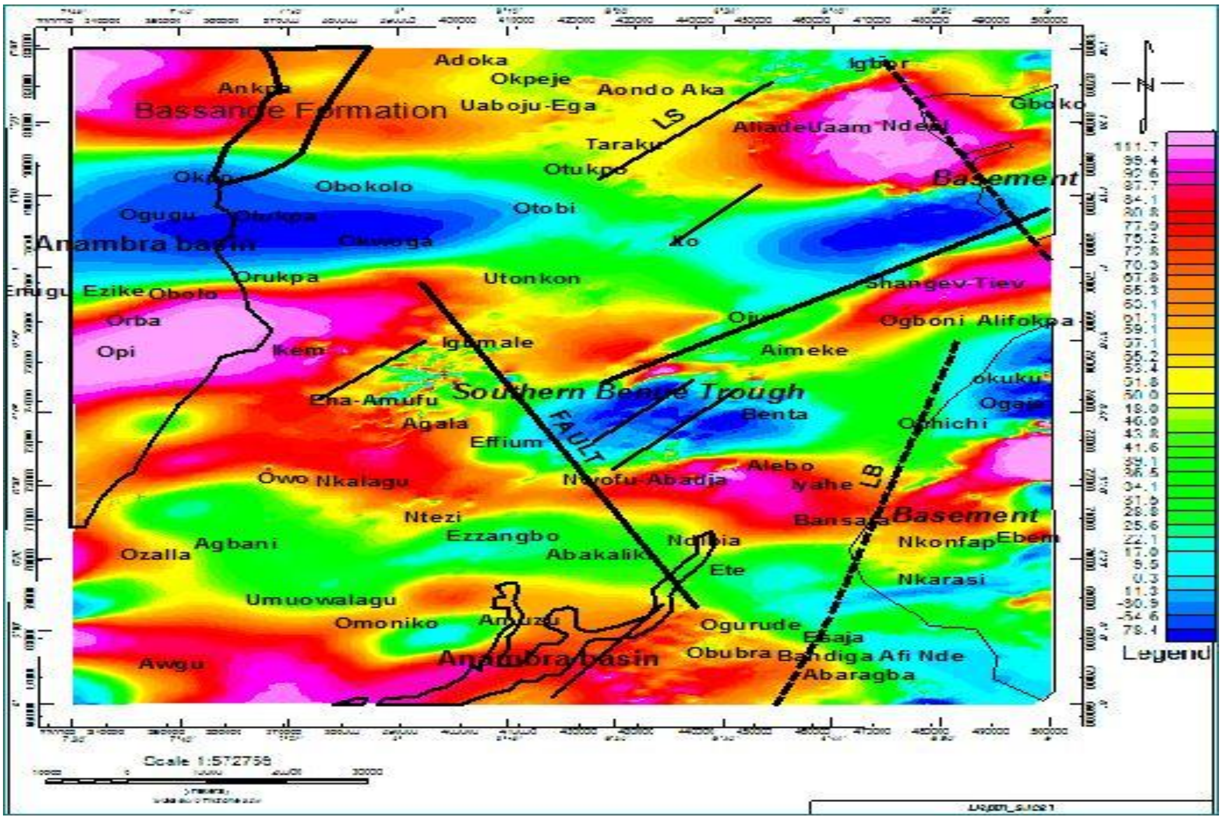

Figure 4: Depth Slice 1: Above 8km Depth. LS= Lineament structure, LB= lithological boundaries and Faults (solid freeform lines used to delineate approximate boundaries of sedimentary basins and basement features have been overlaid).

**Depth Slice 2:** This is structural features at depth greater than 3km but lesser than 8km. This grid revealed shorter wavelength anomalies which are related to shallower sources. The igneous rocks in terms of mafic/intermediate intrusive within the Southern Benue Trough sedimentary basin are responsible for the anomalies revealed in this depth. Short wavelength anomalies named A1-A6 have been delineated and they are dominated within the Southern Benue Trough and around the basement outcropping areas. These anomalies are also in form of both positive and negative residual anomalies. The positive anomalies could be mafic/intermediate intrusive, the negative anomalies obtained could result from granitoids and felsic volcanic rocks or major faults zones (Alagbe and Summonu, 2014). Mineral ores are believed to be prevalent in the study area because of the several shallow magnetic bodies that intruded into the sediments. Shallow lineament structures are abrupt at this depth mainly within the Southern Benue Trough and this reflects tectonics regimes at this area. Dyke intrusive at this area is associated with base metal mineralization in some parts of the area e.g. lead-zinc mineralization around Enyigba area.

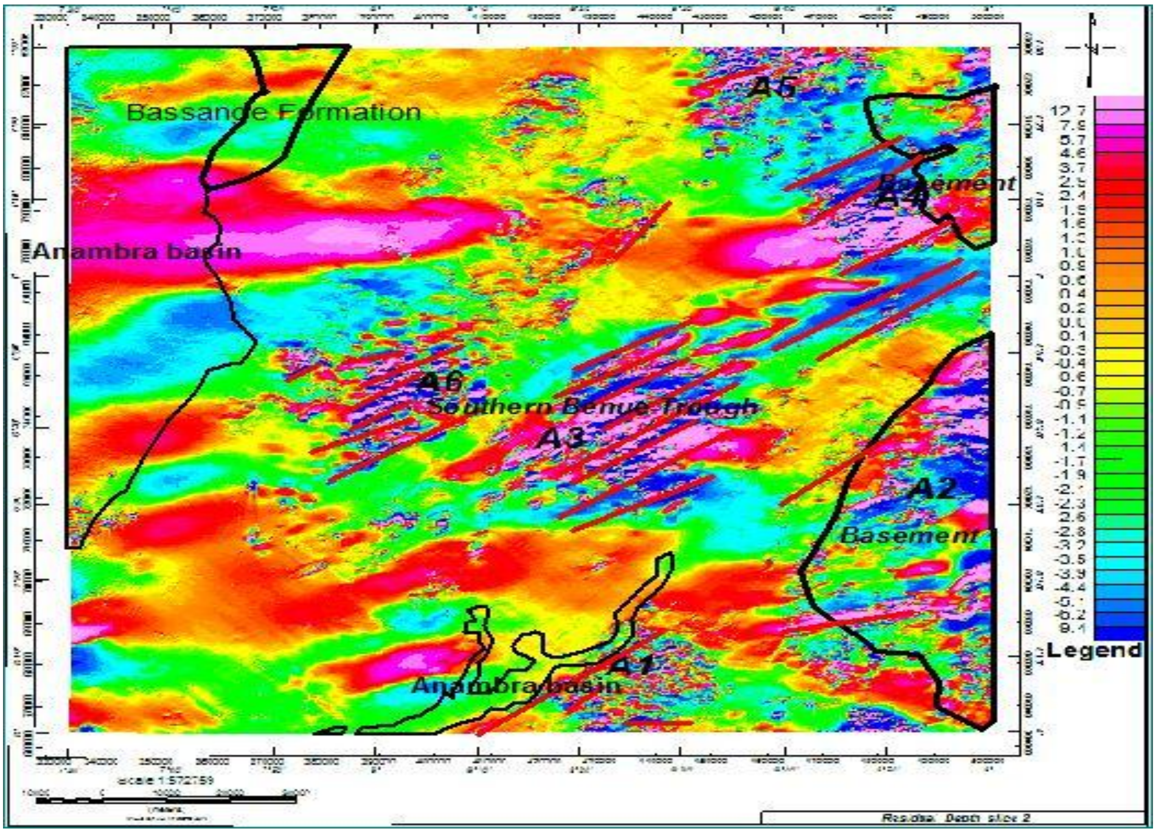

**Figure 5: Depth slice: 2 map representing Shallow source from cut-off depth above 3m (A1 to A6 are shallow magnetic zones revealed by this depth slice, the red bar represent lineament at this depth).**

## Conclusion

The interpretation of high-resolution magnetic data has revealed there are presence of contacts, sills/dikes, pipes/cylinders and spheres geologic bodies located at a depth range of 416.9m -1748.9m within the study area. The SPI technique reveals depth to the basement range between 351.1m (0.351.1km) for the shallow magnetic bodies and 2207.2m (2.2072km) for the deep magnetic bodies. Areas with deep depth of basement can accumulate hydrocarbon. These are areas around Ankpa-Enugu-Ezike-Orukpa-axis in northwestern portion of the area, around Shangev-Tiev axis in the northeastern portion and Iyahe-Basara-Nitrogom axis at the southeastern portion of the study. The depth slice delineated subtler anomalies, lithological boundaries and structures which confirmed the pan Africa tectonic activity (NE-SW trend). Targeted areas for mineral exploration are where these geologic structures and these are mostly within the Benue trough basin.

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