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RESEARCH ARTICLE

EXPLORATION FOR MINERALIZATION AND HYDROCARBON PROSPECTING ZONES OF ABAKILIKI ASPECT OF LOWER BENUE TROUGH

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ABSTRACT

Exploration of structural dynamics using high resolution aeromagnetic dataset of Abakiliki part of the Lower Benue Trough, Nigeria; was deployed for mapping and delineating hydrocarbon prospecting zones, in order to boost the Nation's economy. The aeromagnetic data were subjected to several forms of filtering, reductions, and enhancement techniques for both qualitative and quantitative interpretations. The result of the reduction to equator- total magnetic intensity (RTE-TMI) revealed the magnetic intensity of subsurface rocks ranging from 34.14nT to 61.40nT. This range of magnetic anomalies intensity values extends to the sedimentary covers of Asu River Group, Awgu shale, Eze-AKu shale and Nkporo shale. The second vertical derivative (SVD), Tilt-angle derivative (TDR) and Analytical signal (AS) revealed three (3) major faults; F1-$F^1$1, F2-$F^1$2 and F3-$F^1$3, trending NE-SW, ENE-WSW and NW-SE directions respectively. The depth to top of magnetic source were revealed by the radially averaged power spectrum (RAPS) and Euler deconvolution as 27m - 2.64km as well as <250 m - > 2500 m for shallower and deeper sources respectively. This study demonstrated the efficiency of aeromagnetic methods, with their improved techniques as tools for regional mapping of lithologies and structures that may host important minerals and aid hydrocarbon accumulation and their probable depths.

KEYWORDS

Aeromagnetic, Abakiliki, Lower Benue Trough, Qualitative and Quantitative, Lithostructural, Depths.

1. INTRODUCTION

High resolution aeromagnetic survey of Lower Benue trough aspect of Abakiliki lies within latitudes 6^0oo' and $6^0$30'N and longitudes 8^0oo' and $8^0$30' E. Aeromagnetic geophysical tool was used in detecting the subsurface structures, the depth of the basement and, the sedimentary cover thickness. This non-destructive technique has numerous applications in engineering and environmental studies, including the location of voids, near-surface faults, igneous dikes, and buried ferromagnetic objects like storage drums, pipes etc. Magnetic field variations can be interpreted to determine an anomaly's depth, geometry and magnetic susceptibility. Magnetic data measured in gammas and either collected as total field or gradient measurements are collected in a grid or along a profile with stations spacing.

Aeromagnetic survey is a common type of geophysical survey carried out using a magnetometer aboard or towed behind an aircraft. The principle is similar to a magnetic survey carried out with a hand-held magnetometer but allows much larger areas of the Earth's surface to be covered quickly for regional reconnaissance. The aircraft typically flies in a grid-like pattern with height and line spacing determining the resolution of the data [1].

The Benue Trough of Nigeria in which the study area lies, is a major tectonic feature in West Africa. It is an elongated rifted depression that trends NE-SW merging with the Niger Delta in the south. In the north its sediments are part of the Chad basin succession. Several authors have documented the origin and evolution of the Benue Trough of Nigeria [2-6]. Generally, the Benue Trough is believed to have been formed when the South America separated from Africa. The major component units of the Lower Benue Trough include the Anambra Basin, the Abakaliki Anticlinorium and the Afikpo syncline.

A researcher produced a detailed report on the geology of Abakaliki domain, likened its development to that which occurs in a complete Orogenic cycle including sedimentation, magmatism, metamorphism and compressive tectonism. A researcher suggested that the compression responsible for the large-scale folding and cleavage was directed N155ºE [7]. The magmatism that occurred resulted in the injection of numerous intrusive bodies into the shale of the EzeAku and Asu River Group. A group of researchers generated a regional magnetic field intensity map from aeromagnetic data of the Southern Benue Trough and Niger Delta [8]. The produced regional map showed prominent features and major tectonic trends in the NE-SW direction which when compared with those indicated on the tectonic map of Africa, suggested a linear extension of the Chain and Charcot fracture zone.

The study area is characterized by a number of economic mineral deposit which have generated a lot of interest on the economic importance of this mineral zone. Geological investigations have been concentrated in these areas at different times in search for different mineral deposits. This study aims at contributing to our understanding of the geology and hydrocarbon potentials of this part of the Lower Benue Trough using high resolution aeromagnetic dataset. The aeromagnetic dataset will be used to evaluate the subsurface structures and basal intrusive which control the anomalous mineralization in the area. This is with a view to characterize the subsurface litho-structural features as well as their lateral and depth extents.

2. LOCATION AND GEOLOGY OF THE STUDY AREA

The study area is located within latitudes $6^0$00' and $6^0$30'N and longitudes $8^0$00' and $8^0$30' E (Fig. 1). The Benue Trough was formed as a result of series of tectonics and repetitive sedimentation in the Cretaceous time when South American continent separated from Africa and the opening of the South Atlantic Ocean. The geology of the Lower Benue Trough has been described by several authors [9].

The Lower Benue Trough is underlain by a thick sedimentary sequence deposited in the cretaceous. The oldest sediments belong to the Asu River group (Fig. 2) which uncomfortably overlies the Precambrain Basement Complex that is made of granitic and magmatic rocks. The Asu River group found in the Abakaliki-Afikpo basins has an estimated thickness of 2000 m and is Albian to Ceomanian in age. It comprises of argillaceous sandy shale, laminated sandstone, micaceous sandstone and minor limestone with an inter fingerings or mafic volcanics deposited on top of the Asu River group. Sediments in the area were the upper cretaceous sediments, comprising mostly the Eze-Aku shale. The Turonian Eze-Aku shale consist of nearly 1000m of calcareous flaggy shale and siltstone, thin sandy and shaly limestone and calcareous sandstone [10]. The Eze-Aku shales at the Afikpo Basin for the Amasiri sandstones; while the Nkporo shale is the youngest unit of the Cretaceous sequence and overlies the Eze-Aku shale unconformably. They are Campanian-Maastrichtian in age and are mainly marine in character, with some sandstone intercalations. The sediments of the Abakaliki Anticlinorium are exposed from about 8 km North-East of Okigwe where the folded Eze-Aku shale and the Asu River group are unconformably overlain by the Nkporo shale.

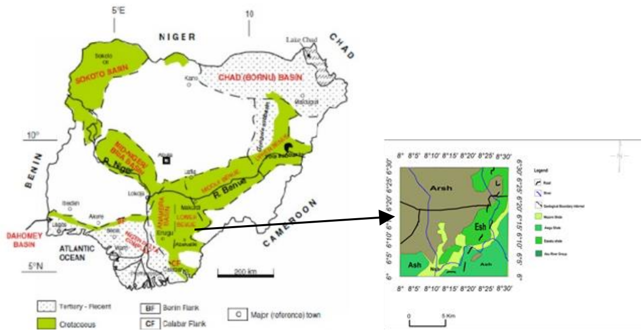

Figure 1: Modified geological Map of Nigeria showing the study area inset Geological Map of Abakaliki, Sheet 303SW [11].

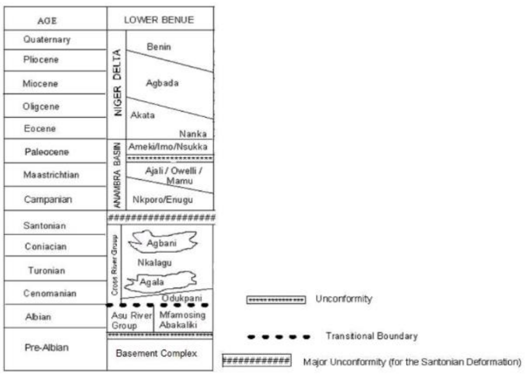

Figure 2: Stratigraphic column of the Lower Benue Trough [12].

3. MATERIALS AND METHODS OF STUDY

This work utilized the aeromagnetic data Sheet 303 of Abakiliki area in the Lower Benue Trough, the aeromagnetic data was acquired from Nigerian Geological Survey Agency, which undertook aeromagnetic survey and digitizing of aeromagnetic data in some parts of Nigeria between 2005 and 2009. The data was collected at a nominal flight altitude of 80 meters along N-S flight lines spaced approximately 1000 meters apart. The aeromagnetic sheet is on a scale of 1:100,000. Diurnal variation effects on the magnetic field, which arise due to solar activities, were recorded using additional unit of base station magnetometer (the ScintrexCS3CesiumVapour). Also, International Geomagnetic Reference Field (IGRF) was subtracted from the total magnetic measurements to get rid of the regional gradient of the earth's magnetic field due to the continual changes in the magnitude and direction of the earth's magnetic field from one place to another [13].

3.1 Methods of Study

The data was processed using Geosoft® Oasis Montaj™ software, other software used included; Surfer and Microsoft Excel.

Data reductions such as: removal of near surface noise (NSN) using Butterworth filter, reduction to magnetic equator, regional field, residual field, automatic gain control (AGC), upward continuation, tilt-angle derivative (TDR), second vertical derivative (SVD), analytic signal (AS), radial average power spectrum (RAPS) and 3D Euler Deconvolution were performed for better result output. The data reductions and enhancements were done using the MAGMAP Step-by-Step filtering processing. Details of technicalities involved in the study can be found in [14-17]. The flow chat in figure 3 shows the data processing stages employed.

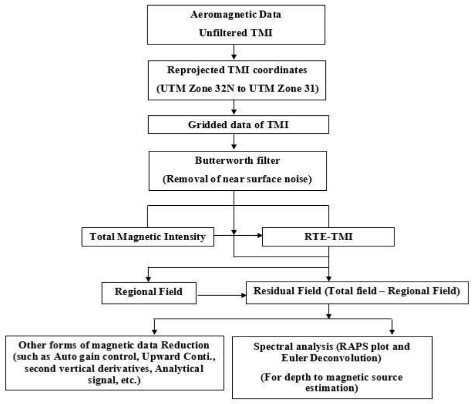

Figure 3: The data processing stages employed

4. RESULTS AND DISCUSSION

The total magnetic intensity map was analysed and interpreted, in order to delineate and characterize the lithologies and structures in the study area that may favour mineralization and hydrocarbon.

4.1 Total Magnetic Intensity (TMI)

The Total Magnetic Intensity (TMI) map (Fig. 4) shows positive magnetic intensity value as high as 93.76 nT which dominated the southern with small segment at the western and northwestern part of the map. The high magnetic intensity at the southern part was cut by an intermediate magnetic intensity (68.48 nT to 86.67 nT). The high magnetic intensity corresponds to the areas close to pyroclast and the intermediate magnetic intensity corresponds to the intermediate depth of basement rocks.

The north parts of the study area are dominated by intermediate magnetic intensity. These areas were interpreted as the intermediate depth of basement rocks. At the central part of the map, fairly low magnetic intensity response (37.38 nT- 68.48 nT) and low magnetic intensity (34.14 nT to 61.40 nT) were identified. These features were interpreted as the deeper depths of the basement rocks. The low magnetic intensity response is also observed at the northern region of the map with a trend of E-W direction and at the northeastern part showing a trend in the same direction. At the eastern and northeastern part of the map there exist low magnetic intensity (34.14 nT to 61.40 nT) and intermediate magnetic intensity (68.48 nT to 86.67 nT) respectively. Both the low and intermediate magnetic intensity correlates with the Eze-aku shale Formation that have further basement rocks. As it can be seen on the map (Fig. 4), faults are observed at the southeastern region of the map showing two major trends, NE-SW and NW-SE trends.

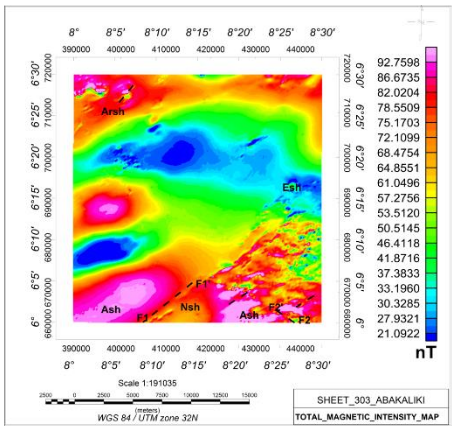

Figure 4: Total Magnetic Intensity (TMI) Image of Abakaliki Sheet 303

4.2 Reduction to Magnetic Equator (RTE)

The Reduction to equator (RTE) of the total magnetic intensity (TMI) map (Fig. 5) shows positive magnetic intensity value as high as 93.79 nT which dominated the southeastern part and extended towards the southern and southwestern part of the study area. Similar feature is noticed at the northwestern part of the study area striking NE-SW direction. The north, north central and northwestern parts of the study area is dominated by rocks with intermediate to high magnetic intensity. The intermediate to high magnetic intensity correlate with the Asu River Group which implies that the depth to basement is between intermediate to high within the study area.

The map (Fig. 5) shows variation in the magnetic intensity, possibly indicating variations in mineral composition of the rocks in the study area. The central part of the map is dominated by fairly low magnetic intensity (34.14 to 61.40 nT) which can be depicted as deeper sedimentary basin within the Asu River Group (Arls). This feature (low magnetic intensity and gradient) is also observed at the northern region of the map with a trend of approximately E-W direction and at the northeastern part showing a trend in same direction. Intermediate magnetic intensity (61.40 to 83.63 nT) feature is seen at the southwestern part of the map trending almost in E-W direction. This body with intermediate magnetic intensity is considered as moderate magnetic intensity and closures which is situated at the Nkporo Shale (Nsh) of shallow sedimentary cover. Features with high magnetic intensity (86.63 to 93.79 nT) is observed at the southwestern and southeastern part of the map showing a trend of NE-SW direction. The trends of subsurface fault along NE-SW is possibly borne out of intrusive pyroclast having high magnetic intensity. Low magnetic intensity (29.39 to 34.14 nT) response is seen at the northern part of the area striking almost in E-W direction. It is also identified at the western part of the map trending in the same direction as that of the one at the northern part of the area. These low magnetic anomalies have huge sedimentary cover within the Asu River Group (Arcs).

As it can be seen on the map (Fig. 5), three faulting systems, F1-F^{1}1’, F2-F^{2}2’ and F3-F^{3}3’were observed with trends of NE-SW, E-W and NW-SE direction respectively. According to a researcher, the variation in trends of the faults was attributed to deeper heterogeneity of the earth crust during the sequence of events at possible opening up of South American and African plate [18].

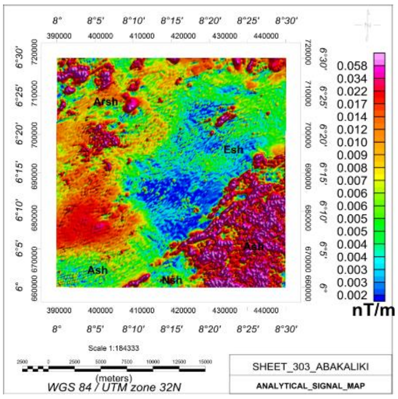

Figure 5: Reduction to Equator of Total Magnetic Intensity (RTE_TMI) Image

4.3 Regional and Residual Magnetic Intensity (RMI)

The TMI data continued upward to depth of 4 km produced a regional field assumed to have resulted from relatively deep-seated structures. On the regional map (Fig. 6), high magnetic intensity (76.97 nT – 80.99 nT) to intermediate magnetic intensity (64.23 nT – 76.97 nT) were observed at the southern part of the map with a trend of approximately N-S direction. At the western, northwestern and northeastern part of the map there exists intermediate magnetic intensity (64.23 nT- 76.97 nT) striking in E-W direction. Low magnetic intensity was identified at the eastern part of the map trending in E-W direction. Clearer image on the general magnetic intensities of the study area is clearly seen on the residual map than what we have on the TMI map because the regional trends have been removed.

The RMI map (Fig. 6) displays different magnetic intensity, with most of them trending in E-W and NE-SW directions. Based on the residual map, the sedimentary rocks in the study area can generally be classified into four (4) major lithologies, (1.) the Asu river Group, (2.) Awgu shale, (3.) Nkporo shale and (4.) Ezeaku shale. These lithologies have differential sedimentary thicknesses and introduction volcanic pyroclastics to the lower Benue trough. The magnetic zone division was based on the intensity of magnetic signatures. On the northern, northwestern part of the map, there exist rocks with high magnetic intensity (12.76 nT- 15.59 nT) having shallow sedimentary cover and intrusive pyroclast within the Asu River Group. The high magnetic intensity could be intrusive pyroclast, galena and associated minerals which may be present within the study area. Low negative magnetic anomalies and polarities (-22.62 nT to -5.22) nT) was observed at the northwestern part of the map. This low magnetic can be attributed to magnetic response coming from deep basement complex within the study area. This part has very thick sedimentary cover within carbonaceous shale of the Asu River Group. High magnetic intensity (12.76 nT- 15.59 nT) is witnessed at the western region of the map which can be considered as the intrusive pyroclast present in shallow sedimentary cover of the Asu River Group. At the southern part of the map, high magnetic intensity is observed. This high magnetic intensity is seen to be separated by intermediate magnetic intensity (2.05 nT- 12.76 nT) are due to basal intrusive within Awgu Shale and Nkporo Shale respectively. Very low negative anomalies and polarities (-5.22 nT- 2.05 nT) observed at the northeastern part of the map are deep seated basement rocks having thick sedimentary cover of the Eze-aku Shale.

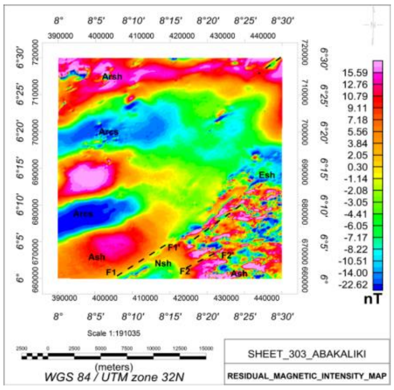

Figure 6: Residual Magnetic Intensity Image of Abakaliki Sheet 303

4.4 Automatic Gain Control (AGC)

The high and low magnetic intensity are intrusive structures situated around the Awgu Shale (Ash) and Nkporo Shale (Nsh) respectively. The map is seen to be dominated by intermediate magnetic intensity (136.72 nT - 138.46 nT) which shows a trend of approximately NE-SW direction. At the northern, western and central region of the map, rocks ranging from fairly low (135.74 nT - 136.72 nT) to intermediate magnetic intensity (136.72 nT - 138.46 nT) demonstrate moderate intrusives within the Asu River Group (Arsh). Small segment of low magnetic anomalies was witnessed at the southwestern part of the map having deep seated intrusive within the Asu River Group (Arls). High magnetic anomalies recorded at the northwestern part of the map, indicates extrusive pyroclast within the Asu River Group (Arsh).

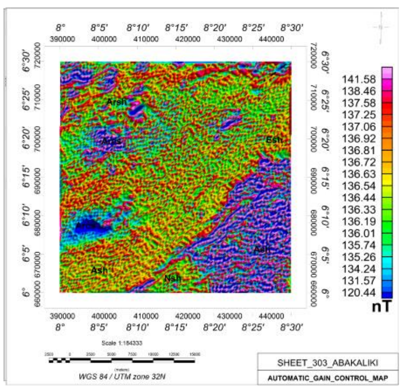

Figure 7: Automatic Gain Control Image

4.5 Second Vertical Derivative (SVD)

The SVD filter decreases broad and more regional anomalies and rather enhance local magnetic responses which are interpreted as structures in the area.

A grey scale is applied to the second vertical derivative of the RTE map. This helped in the identification of features such as lineaments/faults, contacts, edges and trends of various rocks. The grey scale of the second vertical derivative (SVD) image of the RTE gridded data (Fig. 8) enhanced the image by showing major structural and lithological details which were not obvious in RTE image (Fig. 5).

Prominent subsurface lithological contacts and tectonics extending from greater depths to surface, thus affecting the overlain sedimentary sections of: The Awgu shale (marked as A) boundaries with other Formation. Points B, C and D, highlight areas occupied by Nkporo Shale, the Asu River Group and Eze-aku shale respectively. The Awgu shale boundaries are well defined when compared with other Formations in the area.

4.6 Analytical Signal (AS)

To know the source positions of the magnetic anomaly regardless of direction and remnant magnetization of the sources effects that are mostly associated with the RTE, the analytical signal filter was applied to the RTE grid. The significant characteristic of the analytical signal is that; it is independent of the direction of the magnetization of the source. Moreover, the amplitude of the analytical signal can be related to the amplitude of magnetization. The most significant concentrations of mineral deposits and intrusive in an area are correlated with high analytical signal amplitudes [19].

Figure 9 (analytical signal map) shows that, the most prominent subsurface structures and tectonics extending from greater basal basement to the sedimentary covers recorded high analytic signal amplitude that runs in an approximately NE-SW direction along the southeastern part of the area and small segment around the northwestern border of the area. The magnetic amplitude zones possibly due to the subsurface structures i.e high magnetic amplitude zone (> 0.03 nT/m) defined within the Awgu shale (Ash), intermediate magnetic anomalous zone (ranges from 0.02 to 0.03 nT/m) situated around Asu river Group (Arsh), fairly low magnetic anomalous zone (ranges from 0.01 to 0.02 nT/m) lies at (Nkporo shale) and low magnetic anomalous zone (< 0.01nT/m) present within Ezeaku shale (Esh), were delineated (Fig. 9). These different amplitude zones are based on the magnetization contrast, produced by varying subsurface basement mineralogy composition and depth of the magnetic sources.

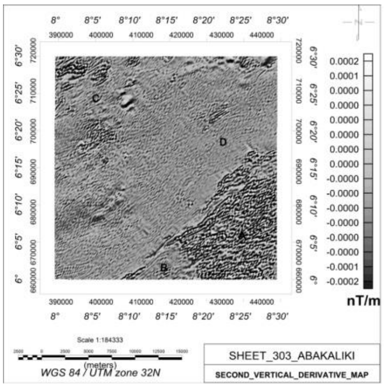

Figure 8: Map of Second Vertical Derivative M

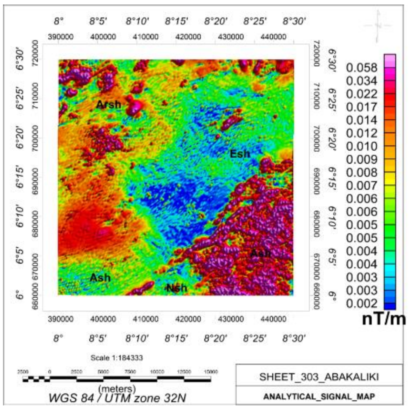

Figure 9: Map of Analytical Signal

4.7 Tilt-angle Derivative (TDR)

To determine structures (lineament, fault, joints, etc.), the contacts and edges or boundaries of magnetic sources, and to enhance both weak and strong magnetic anomalies of the area, the Tilt-angle Derivative (TDR) filter was applied to the RTE grid. The TDR filter attempts to place an anomaly directly over its source [20]. Structural deformations such as faults, joints, and arched zones are well pronounced on grey TDR map (Fig. 10).

From Figure 10, three major fault systems were noticed on this image by observing the abrupt changes between the positive and negative magnetic anomalies. The lineament systems are: F1-F11’, F2-F22’ and F3-F33’ trending NE-SW, ENE-WSW and NW-SE respectively.

4.8 Radially Averaged Power Spectrum (RAPS)

Power Spectrum is a 2D function of the energy and wave number and can be used to identify average depth of source assemblages. Radially Averaged Power Spectrum or Spectral plot (Fig.11) shows the total depth estimate to the top of magnetic sources that produced the observed anomalies in the study area using spectral analysis. The gradient of the layers was calculated based on the wavelength of the magnetic sources. The gradient of the shallower and deeper magnetic sources is 3.51 and 33.15 respectively. Therefore, the total depth estimates to the top of magnetic shallower and deeper sources in the area are 0.279 km (27.9 m) and 2.64 km respectively.

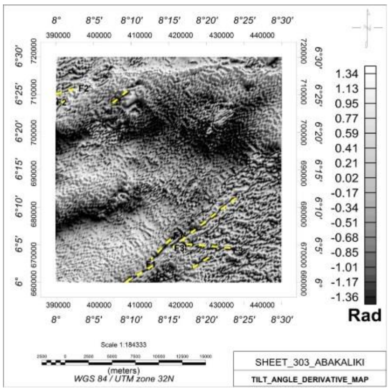

Figure 10: Grey Tilt Derivative Image

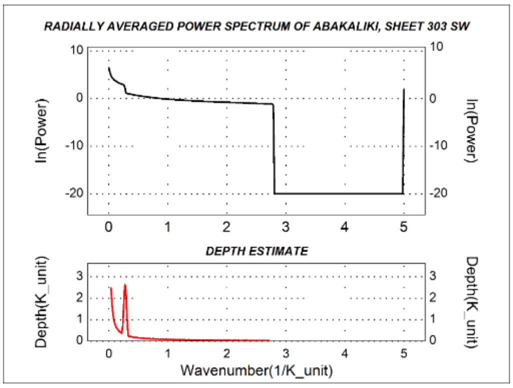

Figure 11: Radially Averaged Power Spectrum/Spectral Plot

4.9 Euler Deconvolution

Euler solution was applied in determining the depth to the magnetic sources in the survey area by using structural Index, SI 0.0 (Fig. 12). This technique was used to calculate the geometry of subsurface structures (geological contacts, lineaments, faults, folds, sills, dykes). The gridding interval enables recognition of any anomaly that is up to 100 minimum wavelengths, hence many solution points which sum up to 34,595. Result with tightest cluster around recognized sources is likely to give the best solution and therefore accepted. Solutions for Lower Benue trough within the Abakaliki sheet document relatively deep magnetic source, greater than 2000 m in depth as seen underlying Asu River Group at the northern, western and southwestern to southern part of the map and reduced progressively towards southeastern part. Euler depths result ranged for regions in the study area such as Abakiliki at the central part of the map (>2000 m).

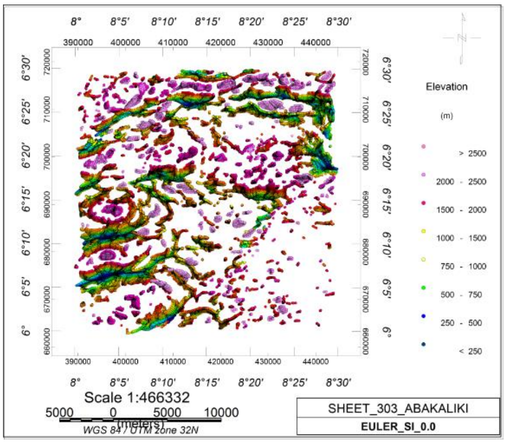

Figure 12: Standard Euler solutions of Abakiliki Sheet 303

5. CONCLUSION

The specific objectives were to explore and interpret the subsurface basements structures and tectonics that could host mineralization and probably hydrocarbon. The significant conclusions are: enhanced filters helped define the lithological boundaries and geological structures such as lineaments, faults, joints, etc. The images have revealed different range of magnetic anomalies values, suggesting different rock types of varying mineralogical compositions, tectonic framework and structural features.

The results of the interpretation of the aeromagnetic dataset shows that the study area is dominated by four to five lithologies owed to differential subsurface basements, tectonics and structures as proven by the total magnetic intensity image, reduction to equator, residual magnetic intensity map, analytic signal image. These lithologies extends to the overlying sedimentary cover Asu River Group, Awgu shale, Eze-aku shale and Nkporo shale.

The interpreted subsurface Faults; FI-F^{1}1, F2-F^{1}2, F3-F^{1}3 elements delineated in the study area were oriented into three major directions which are NE-SW, ENE-WSW and NW-SE respectively as seen on the tilt angle derivative and second vertical derivative.

The total depth estimation to the top of magnetic sources for the study area as demonstrated on the spectral analysis and Euler deconvolution ranged from 0.279 km (27.9 m) to 2.64 km as well as <250 m to >2500 m for shallower and deeper sources respectively.

The aeromagnetic dataset proved valuable in the delineation of most of the lithologies and structures in the study area and estimating the depth to magnetic source body. It serves a valuable tool for characterizing the rock formation in the study area. The varied depth range especially the deeper sources makes the study good for hydrocarbon accumulation but due to diverse intrusive bodies in the study area makes it not viable.

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