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Nickel Deposit Depth Estimation Using Source Parameter Imaging and Euler Deconvolution of Aeromagnetic Data of Bakin Kogi and its Environs in Jema'a Local Government Area of Kaduna state

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Abstract

This study aimed to estimate the depth of Nickel deposit in Bakin Kogi – Dangoma region, which lies between latitude $9^0 11'$and $9^0 27'$N and longitude $8^0 00'$ and $8^0 17'$ E. The study area is located in Jema'a local government area of Kaduna state. The data was gridded using Oasis Montaj® to produce Total magnetic Intensity Map (TMI) of the area, and further subjected to some filtration processes in order to obtain regional and residual map of the study area. Enhancement methods such as first vertical derivative and analytic signal methods were applied to the residual map to delineate the area with potential Nickel deposit. The quantitative method applied were source Parameter Imaging and Euler Deconvolution to determine the various depths of Nickel deposit. From the results of the TMI map and the residual map, the magnetic intensity of the study area was between 32976.5 to 33093.3 nT and 32963.6 to 33072.9 nT respectively with Bakin kogi-Dangoma region, having the highest magnetic intensity of about 33093.3nT and 33072.9nT respectively. The study area has a high magnetic intensity due to nickel deposit because Nickel ore environment are notable with recognizable "magnetic stratigraphy", prospective mafic-ultramafic contact, typified by strong magnetic contrast. Abrupt changes in the magnetic intensity infer position of the outer contact of a Nickel bearing zone. The results on the superimposed analytic map on the lineament map showed regional lineaments in Bakin kogi-Dangoma region trending NE -SW, ENE – WSW and NNE – SSW directions. The fractures and faults seen around the study area were strongly associated with minerals deposit. The results of Source Parameter Imaging (SPI) gave a depth of shallower magnetic sources ranges from 92.7 to 116.0 m with an average depth value of 104.35m while the depth of deeper magnetic sources ranges from 651.2 to 976.2 m with an average depth of 813.7 m. The results obtained from 3D Euler deconvolution which was associated with dykes $(SI = 1)$ anomaly produced at a shallower depth range of $100 - 700\ m$. Results obtained, shows a correspondence between the depths results obtained from the SPI and that of the Euler Deconvolution methods, indicating correlation in the magnetic depth estimation.

Keywords: Aeromagnetic; Nickel; 3D Euler Deconvolution; Source Parameter Imaging; Magnetic Depth Estimation

I. Introduction

Nickel with a chemical symbol Ni and atomic number 28 is a ferromagnetic element found in d-block of the periodic table known as transition block and is usually hard and ductile. In its purest form, its chemical activity is high and under normal and standard condition, it takes longer time for larger pieces to react with air to form oxide layers, a process that makes it to be resistance to corrosion. However, the purest form of nickel in the earth's crust can only be found in ultramafic and in the interiors of larger nickel-iron ore (meteorite) in a very small amount. Laterites formation is resulted from erosion of ultramafic rocks which is believed to be associated with Nickel deposit and usually have a very clear distinguishable magnetic anomalies [1]. At the other hand, deposits of nickel sulfide which are also highly magnetic are found in magnetic igneous rocks [2]. This nickel is also found in both inner and outer core of the planet earth as a mixture of iron and nickel which is responsible for the earth's magnetism [3]. One major and appreciable method to harness these important minerals is magnetic method (exploration). This magnetic exploration can be done on land, at sea and in the air. For areas with difficult terrain, survey using airborne magnetometer is more advantageous [4]. This airborne magnetic survey has numerous advantages in that, the survey is cheaper per kilometer and besides, it is done with appreciated high speed. In airborne or simply aeromagnetic survey, a measuring device known as magnetometer is usually attached an aircraft. The air craft is flown in a grid-like pattern over the targeted area at a particular height and spacing which determine the resolution of the data. The variations in the intensity of the earth's magnetic field is measured by the magnetometer as the air craft flies all over the area of interest. These variations are the major tools used in the production of aeromagnetic map of any study area. The aeromagnetic map basically indicates magnetic anomalies emanating from the source bodies [5]. Rocks beneath the earth's surface are generally magnetic but only those ones with reasonable magnetic grains produce significant magnetic anomalies. Of all the rock types, sedimentary rocks tend to have the lowest magnetic content while metamorphic and igneous have higher magnetic content in them [6]. The underlying basement rocks within the sedimentary successions such as dykes, volcanic rocks etc. as well as due to geological iron contamination and antigenic alterations in sedimentary rocks are likely caused by hydrocarbon migration [7].

Nigeria presently largely depends on crude oil as her major source of internally generated revenue. This Nigeria dependence on crude oil is not healthy to her country as it contributes to global warming through green-house effect and contamination of lands during exploration and emission of carbon monoxide due to incomplete combustion of fuel, and will in the future be exhausted. Aside the global warming issue, Nigeria's income will be in danger whenever there is a downfall in crude oil price and this calls for a search for a more sustainable source of income. Solid minerals such as Nickel have significant economic values. Nickel for instance, is used to manufacture numerous alloys (such as USA coins and some expensive jewelries) because of its resistance to corrosion. Thus, solid minerals globally boost economy and even Nigeria's solid minerals has been estimated by researchers to worth several hundreds of trillions of dollars, having majority of it (about 70 percent) buried in the bowel of Northern Nigeria [8]. In order to keep the country going, the federal government through the Federal Ministry of Solid Minerals Development embarked on a search for alternative to crude oil in order to diversify her economy which led to the discovery of Nickel deposit in August, 2016 in Bakin Kogi, a village close to Dangoma in Jema'a local government area of Kaduna state. This suspected Nickel deposit at Bakin Kogi axis as reported by [1] has no any substantive evidence of primary or secondary nickel sulfides which may be attributed to the low sulfur fugacity during ore formation. However, it was assumed that the ore mineral of native nickel in the regolith occurs predominantly in the form of a circular balls with diameter between 0.1 to $5mm$ compare to the minute flakes or blebs usually less than1 mm size in the serpentinized host rock. What is notable worldwide about native nickel occurrences is that, they are only associated with serpentinized ultramafic rocks and never as hydrothermal deposits. Until adequate geological data and research work are available on the subsurface characteristics of the host rocks of the Bakin Kogi - Dangoma deposit, a discussion of Nickel deposit around Bakin Kogi - Dangoma region remains speculative [1], but because of the known spatial association between native nickel and serpentinized ultramafic rocks, it is reasonable to assume that the origin of the Bakin Kogi - Dangoma nickel deposit is connected to the parent ultramafic bedrock and the serpentinization process that affected such rock during low grade regional metamorphism of the Precambrian meta-sediments and meta-ultramafites. This research was therefore, carried out to investigate the various depths of Nickel deposit around Bakin Kogi area.

II. Location and Geology of the Study Area

Bakin Kogi is located within the basement complex area of the northern Nigeria and is underlain by Pre-cambriam basement rocks which are mostly granites. The study area lies between latitude $9^0 11'$ and $9^0 27'$ N and longitude $8^0 00'$ and $8^0 17'$ E. The study area is in Jema'a Local Government area of Kaduna state and its population has grown tremendously in the last 30 years [9]. The nickel deposit is located within the villages of Bakin Kogi and Dangoma in Jema'a local government area (LGA) of southern Kaduna, Kaduna State. The area has an average elevation of about $650\ m$ above sea level, is of low relief with slightly undulating topography and low-lying outcrops and a few prominent ridges of weathered granite scattered over the landscape. The geology of north-central Nigeria shows that the nickel deposit is localized within the Precambrian Basement Complex which is composed of the mostly Archean migmatite-gneiss complex, Pan-African Older Granites and the Proterozoic schist belts intruded by minor meta-ultramafic bodies and pegmatite dykes. The Bakin Kogi area lies east of the N-S trending supracrustal schist belts of northwestern Nigeria and is underlain by migmatites, gneisses, (serpentinite) and granites. The granite gneisses which are scattered over the area are composed mostly of granoblastic biotite and biotite-hornblende gneisses [9]. The geological map of the study area is given by Fig. 1.

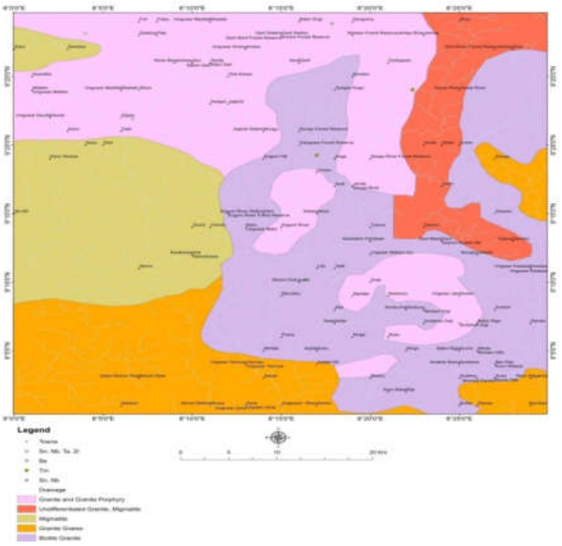

Fig. 1 Geological map of the study area [10]

III. Materials and Method

The materials used for this research paper include one sheet of Aeromagnetic data (Sheet No. 188), Geological map of the study area, suffer 13 software, Oasis Montaj 8.4 software and Micro Excel. The high-resolution aeromagnetic data of the study area was procured from the Nigerian Geological Survey Agency (NGSA). A 3x Scintrex CS2 cesium vapour magnetometer was used to obtain the aeromagnetic data in 2016 by Australian mining company (Comet Minerals Company Ltd). The survey was flown at 80 m elevation along flight lines spaced 500 m apart [1].

A. Data Processing

The methods employed in this research were enhancement methods to generate total magnetic intensity map, regional map and Residual map of the area. Source Parameter Imaging (SPI) as well as Euler Deconvolution methods were employed to determine the positions and various depths of Nickel deposit around the study area. The important of Source Parameter Imaging (SPI) in magnetic survey analysis cannot be overemphasized. SPI is a technique based on the extension of complex analytic signal (AS) to estimate magnetic depths; it is also known as local wavenumber [10]. This SPI method was used by [11] to determine the depth of the magnetic sources. Let T be a magnetic field and K be a local wavenumber, then:

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

The depth of any magnetic source can easily be calculated with high level of accuracy as it uses second order derivatives and consequently, the interference of the anomaly features can be significantly reduced [12]. This method produces accurate depth estimation 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 [10]. The SPI computes source parameters from gridded magnetic data. Solution grids show the edge locations, depths, dips, and susceptibility contrasts. The depth estimation is independent of variables such as magnetic inclination, declination, dip, strike and/or remanent magnetization [11]. Practically, when this method is employed, the direction at each grid point is first estimated on the gridded data. The vertical gradient is computed in the frequency domain, and the horizontal derivatives are computed in the direction perpendicular to the target using the least-squares method [12]. The depth to magnetic source (Nickel) in this work was determined through several mathematical processing from various grids using Oasis Montaj software® (version 8.4). The residual grid was pre-processed as input grids dx, dy and dz which were later served as input grids for SPI processing. SPI method is much more sensitive to noise at higher derivative order and hence, the use of the first order derivative. Therefore, careful filtering of data was ensured so as to have good estimates of the local wave number and hence the various depths obtained. The real aim of employing SPI method is that the image (map) produced can be easily interpreted any Geophysicist by merely looking at it.

Let Z = source depth and n = assumed source geometry analogous to structural index, $n = 1, 2, 3$, then:

$$Z = \frac{n}{K} \quad (2)$$

B. Euler Deconvolution Method

Euler Deconvolution method basically provides automatic estimates of magnetic source locations as well as their corresponding depths. This method has become very useful in magnetic analysis because it provides delineation of trends and depths. The extent of the depth estimation depends on the choice of a structural index (SI) [13]. This structural index is just a description of scaling behavior based on Euler homogeneity and has a fixed integer number such as $n = 1,2,3$. Euler deconvolution is expressed as:

$$(x - x_0)\frac{dT}{dx} + (y - y_0)\frac{dT}{dy} + (z - z_0)\frac{dT}{dz} = n(B - T) \quad (3)$$

Where (x_0, y_0, z_0) represent the position of a 3D magnetic source whose total field T is detected at (x, y, z). The source position (x_0, y_0, z_0) and the background field are obtained by solving the Euler equation. If n is too low the depth estimate (z_0) will be too shallow, and if n is too high, the depth will be overestimated. The horizontal coordinates are much less affected. An effective strategy is to work with all values of n between 0 and 3, in increments of 0.5. This will account for the geology not being properly represented by any one of the idealized model shapes, and also it has been shown that for more realistic models n varies with depth and location.

IV. RESULTS

The aeromagnetic data procured from NGSA was gridded to yield the Total magnetic intensity (TMI) map of the study area (Fig. 2) using Oasis Montaj software®. The TMI map of the study area displayed regions of different magnetic intensities between the ranges of 32976.5 to 33093.3 nT; this is an indication that the study area is characterized with low and high magnetic signature, and this variation in the intensity could be due to the differences in magnetic susceptibilities.

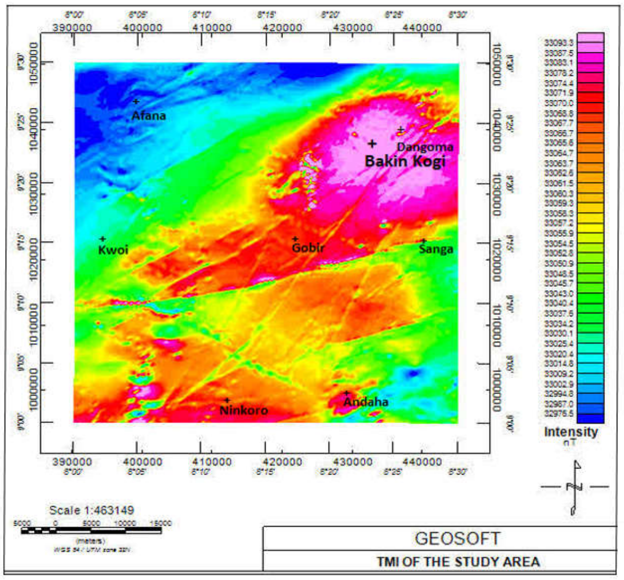

Fig. 2 Total Magnetic Intensity Map of Study area

The TMI was further subjected to filtering to remove the regional field within (Fig. 3) in order to obtain the residual map (see Fig, 4). The residual map of the study area revealed magnetic field intensity ranges from 32963.6 nT (minimum) to 33072.9 nT (maximum). The study area has the highest magnetic intensity, an indication of the presence of a highly ferromagnetic signature.

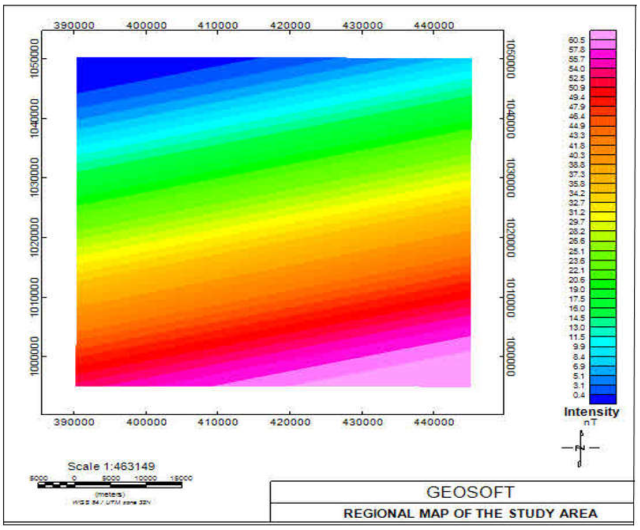

Fig. 3 Regional Magnetic Map of the study area

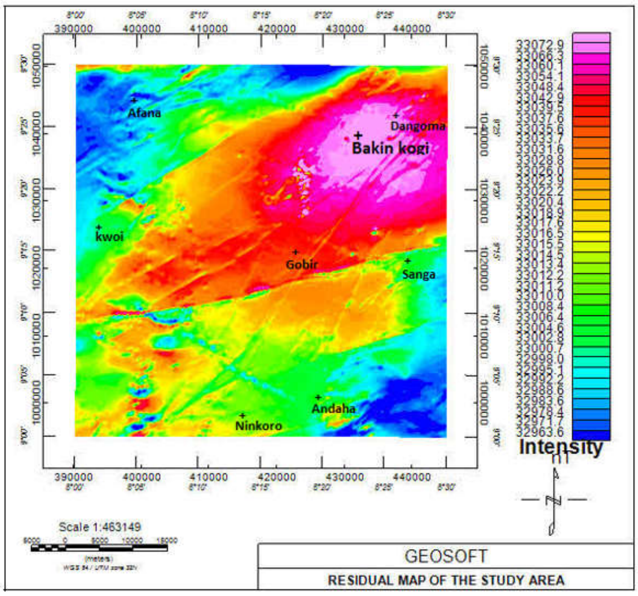

Fig. 4 Residual map of the Study area

The SPI map and SPI legend (Fig. 5) displayed different colours with different magnetic susceptibilities contrast around the study area. The negative values on the legend depict the depth of the magnetic body. The areas occupy by shallow sediments are indicated by pink colour (92.7 to 116.0 m) while the blue colour on the legend with range from 651.2 to 976.2 m depicts areas of deep lying magnetic bodies.

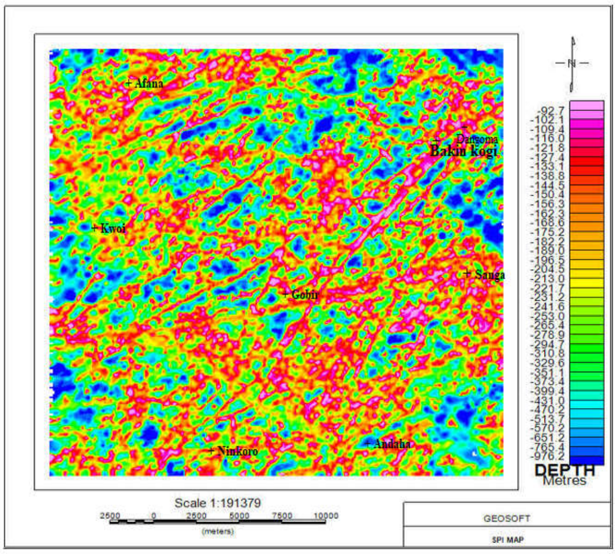

Fig. 5 SPI Map of the study area

Further filtering in order to enhance and delineate high frequency features more clearly where they are shadowed by large amplitude (low frequency), first vertical derivative was performed. This filtering process usually sharpens the edges of anomalies to make the boundaries very prominent for better geologic interpretation of the causative body of the anomalies. During this process, the shorter components were amplified at the expense of longer wavelengths. When compared the map of the first vertical derivative (Fig. 6) and the Total Magnetic Intensity Map, it would be seen that some subsurface features which were not seen became more clearly shown in the first vertical derivative map (Fig. 6).

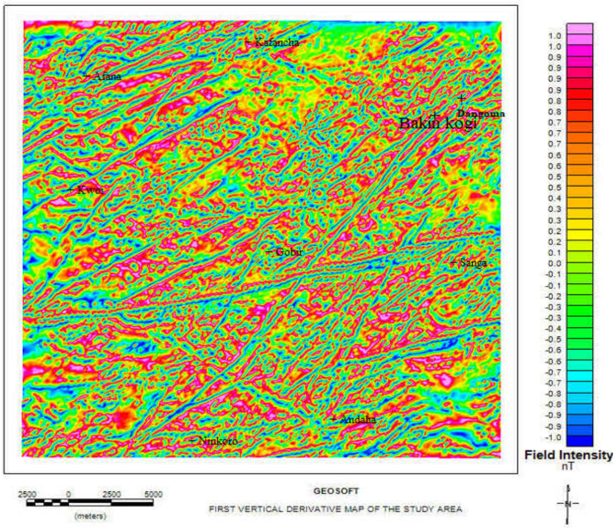

Fig. 6 First Vertical Derivative Map of the study Area

The depth and geometry of the subsurface structures within the study area were determined using the Euler deconvolution technique with the choice of $SI = 1$ (see Fig. 8). The map obtained revealed various depths of the magnetic anomalies. The depths vary from $< 100\,m$ (shallower depth) to $> 6000\,m$ (deeper depth); with the depth of magnetic body around Bakin Kogi region between 100 and 700 m (Fig 8). The result revealed several NW trending lineament as depicted in Fig. 7. These lineaments are indications of fractures and faults which are associated with mineralization [1]. The depth solutions around Bakin Kogi region showed the depth solutions were increasing towards the NW direction. This could indicate that the deposit is dipping inward; the deposit bearing may be plunging in the NW direction.

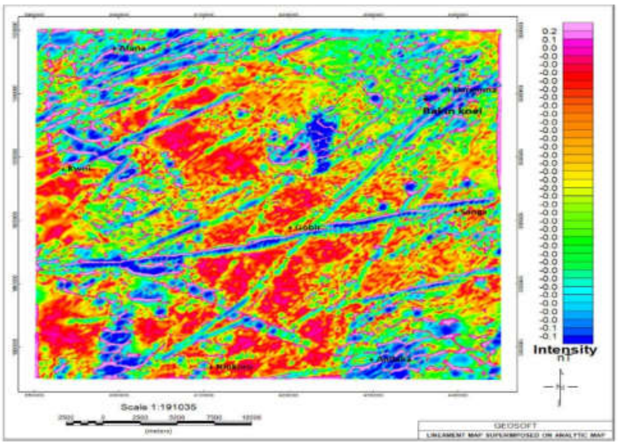

Fig. 7 Superimposed Lineament on Analytic Signal map

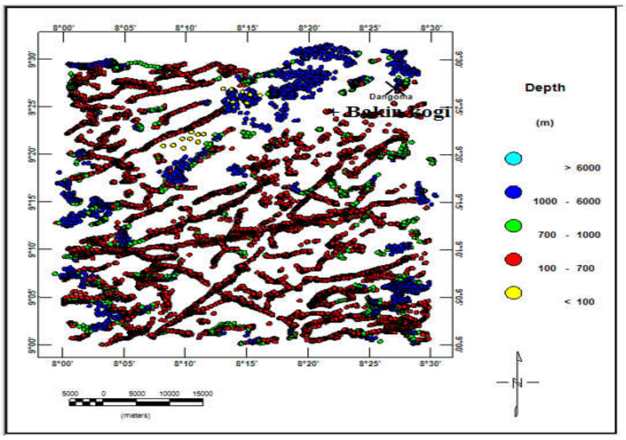

Fig. 8 Euler dyke($SI = 1$)solution of the study area

V. DISCUSSION

Nickel ore environment are notable with recognizable "magnetic stratigraphy", prospective mafic-ultramafic contact typified by strong magnetic contrast. The deposit may be characterized by areas of positive magnetic anomaly within the ultramafic pile. The mafic-ultramafic contact is usually associated with change in magnetic intensity which is about

$33100\ nT$ [14]. Abrupt changes in the magnetic intensity have been related to inferred position of the outer contact of a Nickel bearing zone [15]. Bakin Kogi area is situated in a region with high TMI (about $33100\ nT$) which is bounded by a low TMI region (about $32976.5\ nT$) (see Fig. 2). An abrupt change of magnetic intensity about $33072.9\ nT$, is also observed within the region of Bakin Kogi axis in the residual magnetic intensity map as shown in Fig. 4. [1] Reported the nickel mineralization in Bakin Kogi - Dangoma axis to be containing local nickel dispersed within a deeply weathered regolith overlying a serpentinized ultramafic host rock. According to him: The nickel mineralization is predominantly a residual deposit that occurs within a $6-10\ m$ thick deeply weathered. The result obtained from the Source Parameter Imaging of the study area has the depth of the magnetic sources ranging between $92.7\ to\ 976.2\ m$, with magnetic source depth at Bakin Kogi between $92.7\ to\ 116.0\ m$. Although there is no report that the weathering extends to the depth to the top, it is believed the high magnetic intensity around Bakin Kogi axis is as a result of the mafic host rock underlying within the subsurface. In nickel exploration, a processed magnetic map can define the contacts of the host rock as well as linear features that may represent magnetic dykes containing sulphide. Magnetic lineaments have been spatially related to sites of nickel mineralization [16]. The weathered regolith is believed to have been responsible for the manifestation of lineaments in the results of TMI, residual magnetic intensity, and the superimposed lineament-analytic signal map. The results on the superimposed analytic map on the lineament map showed regional lineaments in Bakin Kogi-Dangoma region trending NE -SW, ENE – WSW and NNE – SSW directions (Fig. 7).

The result of the solution Euler deconvolution revealed several NW trending lineaments which are hitherto unexposed by previous techniques. These lineaments could represent the associated fault systems reported around Bakin Kogi region [1]. The depth solutions around Bakin Kogi region suggests the weathered regolith could be $100\ m$ deep. Also, nature of the depth solutions around Bakin Kogi - Dangoma region shows the depth solutions are increasing towards the NW direction. This could indicate that the deposit is dipping inward; the deposit bearing may be plunging in the NW direction.

VI. Conclusion

The interpretation of the aeromagnetic data of the study area was done using Source Parameter Imaging and Euler convolution methods to estimate depths of Nickel deposit around Bakin Kogi region, in Jema'a local government area of Kaduna state. The depth of shallower magnetic sources ranges from 92.7 to $116.0\ m$ with an average depth value of $104.35\ m$ while the depth of deeper magnetic sources ranges from 651.2 to $976.2\ m$ with an average depth of $813.7\ m$. The lineaments on the superimposed-analytic signal map showed regional faults and fractures trending from NE to SW of the study area, that is from Sanga through Gobir axes. The area around Bakin Kogi – Dangoma showed the presence of folds and there is indication of synclinical axis at some places close to Kwoi. The results obtained from 3D Euler deconvolution which was associated with dykes ($SI = 1$) anomaly produced at a shallower depth range of $100-700\ m$. Even though there has not been any research work reported on the depth of Nickel deposit around Bakin Kogi – Dangoma axis, [1] however reported that the Nickel deposit around the study area was believed to be between 6 and 10 m deeply weathered. From the entire results, there is similarity between the depths results obtained from the SPI and that of the Euler Deconvolution methods. This means that the nickel could be found within the determined depths at the studied area.

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