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RESEARCH ARTICLE

INTERPRETATION OF MAJOR STRUCTURES WITHIN THE BASEMENT REGION OF BENUE-NIGER CONFLUENCE FROM AEROMAGNETIC AND RADIOMETRIC DATA KOGI STATE NIGERIA

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ABSTRACT

Interpretation of Aeromagnetic and Radiometric Data covering the basement region of Benue-Niger confluence was executed to delineate major structures and other geologic frame works of mineral interest. The study area which hosts the Benue-Niger confluence also encloses two major geologic units which are basement complex and sedimentary basins. The Aeromagnetic data set comprising sheet 227 (Koton-Karfe), 247 (Lokoja) and 267 (Idah) was enhanced to reveal geologic structures while radiometric data was analysed to map lithology and zones affected by hydrothermal alterations. A set of mathematical algorithms was used to enhance the data for interpretation. First Vertical derivatives, Analytical Signal and Euler deconvolution filters were applied to the Aeromagnetic data while Ratio and Ternary images of the three radiogenic elements were obtained for the radiometric data. Magnetic signatures from the TMI showed a mixture of high and low susceptibility below koton-karfe due to intrusion of oolitic iron ore within the sedimentary formation. Lokoja regions recorded highest susceptibility of 165 nT due to magnetic signatures emanating from exposed basement rocks. The southern Idah regions recorded relatively low susceptibility. Result of First Vertical Derivative revealed near surface mineral potent structures labelled F1 – F8, cringing surface features B1, B2 and B3. Analytical signal revealed high amplitudes range of 0.174 to 0.579 cycles for magnetic sources majorly at the basement regions, while low amplitude range of 0.021 to 0.157 cycles were recorded around the sedimentary regions. Euler depth analysis revealed shallower depth to sources in the basement and deeper depth to sources in the sedimentary regions due to thick overburden. Radiometric signatures from the K/Th ratio map revealed portions around Latitude 8°00' NW and 7°30' SW shaded in pink colour and having values above known threshold of 0.2 %/ppm to be hydrothermally altered. Mapping of lithology from Ternary map revealed K-Feldspar mineral bearing rocks dominated the NW and SW regions, while sandstones, ironstones, mudstones, shale, alluvium and other fluvial sedimentary lithologies dominated the sedimentary North-east and South-Eastern regions. The western regions (NW and SW) hosted the major structures in form of magnetic lineaments trending NE-SW and E-W which also coincided with regions delineated to be hydrothermally altered and apparently represents the most prospective regions of mineralisation in the study area.

KEYWORDS

Hydrothermal alteration, Major structures, Basement rocks, Lineaments, Mineralization

1. INTRODUCTION

Geophysical methods are often the most essential and effective tools for probing the earths subsurface for mineral exploration and other geophysical investigations of economic importance. Amongst the various Geophysical methods for mapping the earth, Air-born geophysical methods (Aeromagnetic and Radiometric) offers a cost effective and time saving means of surveying large areas and delivering high resolution data that could help delineate mineral hosting geologic frame works with high accuracy and precision. Radiometric data when analysed can shows variation and concentrations of radioelements (K, Th and U) which helps in mapping lithology and providing evidence of hydrothermal alterations. Hydrothermal alterations provides the bases for understanding how radioactivity or volcanic occurrences in the earth crust results in the heating, movement and crystallisation of mineralised liquids (hydrothermal solutions) along geologic structures such as faults, fractures and shear zones. The evaluation of geologic structures from aeromagnetic data could reveal lineaments that host minerals as minerals within intruded basement rocks are structurally controlled (Haruna, 2017).

Solid mineral exploration offers a range of colossal benefits which Nigeria stands to enjoy considering the abundance of solid mineral resources traceable in almost every state. Previous studies has identified over twenty minerals at various locations within Kogi state (Fatoye, 2018). Very few exploration of these minerals are achievable due to lack of precise location of these minerals and poor commitment by various government agencies. Solid minerals of economic value such as gold, marble, limestone, iron ore and gemstones are scattered across the vast land mass that make up the state. Exploration for these mineral could

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remain elusive until a comprehensive geophysical exploration is carried out that will delineate the precise location in coordinate and depth where these ores are located. The availability of such a database will become a tool that will attract investors who are interested in mineral exploration. This research is therefore aimed at delineating and interpreting the major structures within the basement region of Benue-Niger confluence area of Kogi state and its significance or motivation is to highlight the mineral potential of study area which when explored could serve as alternative economic resource to the Nation. This will increase the revenue accrued to the nation as well as help in diversifying the revenue base from crude oil to other sources.

2. Location and Geology of Study Area

The study area is part of the confluence region denoting the region where river Benue and river Niger coincide. It is situated at the left hand side of the river Niger cutting across Koton-Karfi, Lokoja down to Idah. It is bounded by Latitude 7.0°N to 8.5°N and Longitude 6.5°E to 7.0°E. The study area projected from Administrative map of Nigeria is shown in figure 1 below:

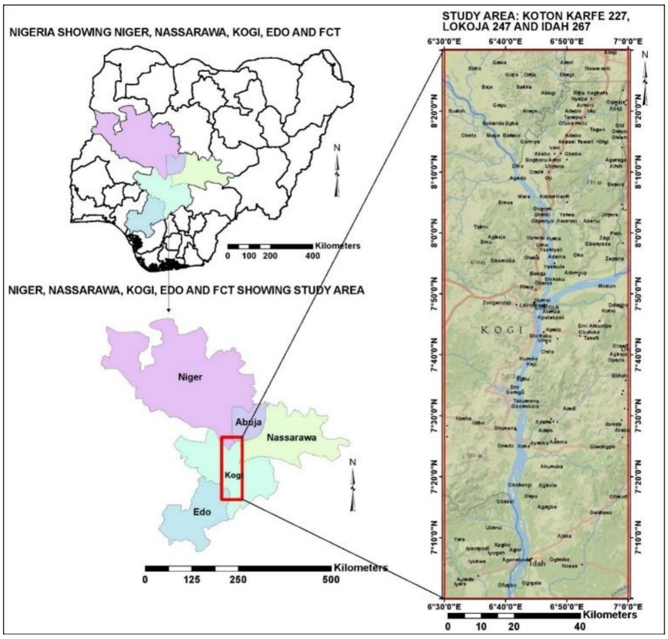

Figure 1: location of Study Area projected from Administrative Map of Nigeria.

2.1 Geology of Study Area

The geological setting of Kogi State which houses the study area is unique in view of the occurrence of the two major components of Nigerian geology (Basement Complex and Sedimentary Basin). Approximately, half of the State is covered by crystalline Basement Complex while the other half is covered by Cretaceous to Recent sediments (Fatoye, 2018). The area of interest covers Koton-Karfe at the top, Lokoja at the middle and Idah at the bottom. Koton-karfe area is occupied by part of Nupe Basin and shows the prevailing principal litho-facies to be sandstones which mostly strike N-S and have low dips. The basal lithology is usually the coarse pebbly sandstone with no lateral variation. Geometrically, the sand bodies are tabular to elongate and with some sandbars, made up of multiple build-up of sand bodies (Adeleye, 1974). Several outcrops of the sandstones sections along the Lokoja - Abaji Road are preserved by a hard indurate top layer of laterite (Akanmu, 1998). Lokoja area fall under the banded iron Formation of Nigeria, generally they occur in metamorphosed folded bands, associated with Precambrain basement complex rock which included low meta-sediments, high grade schist, gneisses and migmatites. Included in this group are well known Lokoja-Okene occurrences notably at Itakpe, Ajabanoko, Chokochoko, Toto Muro and more specifically to the study area is Agbaja and Taijimi. The banded iron Formation occurs sporadically in narrow bands and lenses inter-bedded with massive green phyllites, feebly developed slaty rock and amphibolites. The dominated lithologic units in the area are gneisses of migma-tite, biotite and granite which are typical traits of the Nigerian western Basement geological. Idah area is predominantly occupied by rock types such as sandstone, shale, limestone, clay and mudstone which are characteristic features of sedimentary basin geology.

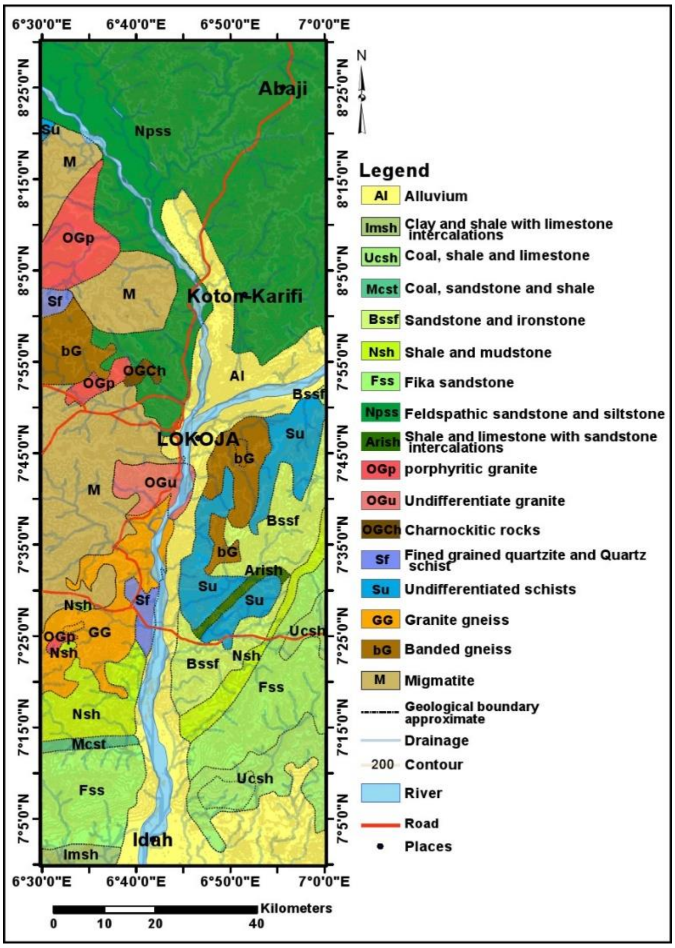

Figure 2: Geological map of Study Area (adapted from NGSA, 2009)

3. Materials and Method

3.1 Data source

The Aeromagnetic and radiometric dataset used for this study was obtained from the Nigeria Geological Survey Agency (NGSA), an agency of government officially saddled with the statutory role of providing up-to-date Geoscience information related to rocks, minerals and groundwater resources of the country. The details of data specifications is shown in the table 1 below:

Table 1: Data Parameter and Specifications (NGSA, 2010)

Survey Parameter	Specification
Data Acquired by:	Fugro Airborne Surveys
Time Range	2005 – 2009
Magnetic data Recording Interval	0.1 seconds or less
Sensor Mean Terrain Clearance	80 meters
Flight Line Spacing	500 meters
Tie Line Spacing	5000 meters
Flight Line trend	135 degrees
Tie Line trend	45 degrees
Equipment: Aircraft	Cessna Caravan 208B ZS-FSA, Cessna Caravan 208 ZS-MSJ,
Equipment: Magnetometer	3 x Scintrex CS3 Cesium Vapour

3.2 Method

The methods employed in this research includes:

- Production of Total magnetic Intensity map from obtained gridded data.
- Computation of Vertical derivatives and Analytical Signal to delineate structures and lineaments.
- Computation of Euler deconvolution to determine the depth of causative bodies.

- Computation of radioelements ratio to access the variation in concentrations that will aid detection of hydrothermal alteration.
- Computation of Ternary map by combining the data of Potassium K (in red), Thorium Th (in green) and Uranium U (in blue) to map lithologies.
- Correlation of delineated structures with mapped lithologies and zones of hydrothermal alterations to map regions of mineralisation.

3.3 Theory of Method

A set of mathematical algorithms used to enhance the data for appropriate interpretation is as follows:

- First Vertical Derivative Filter

The application of the vertical derivative filter to a magnetic data is to improve the shallowest magnetic features and suppress the deeper anomalies in the data (Geosoft Inc, 1996). The filter attempts to attenuate the long wavelength regional features within a potential data and in the same vein accentuate the shallow features that are high in frequency of occurrence. The function can be mathematically related as:

$$L(r) = r^n \quad (1)$$

Where n depict the order of differentiation generally 1 or 2, r signifies the wavenumber in radians per ground unit and L is cycle/ground unit in which the survey was conducted e.g. metres, feet, Kilometre etc.

- Analytical Signal Amplitude

The analytical method gives the amplitude response of an anomaly. This filter applied to magnetic data is aimed at simplifying the fact that magnetic bodies usually have positive and negative peak associated with it, which may make it difficult to determine the exact location of causative body. For two dimensional bodies a bell shaped symmetrical function is derived and for a three dimensional bodies the function is amplified of analytical signal. This function and it derivatives are independent of strike, dip, magnetic declination, inclination and remanent magnetization (Debeglia and Corpel 1997)

The analytic signal is a function related to magnetic fields by the derivatives:

$$AS = \sqrt{\left(\frac{\partial A}{\partial x}\right)^2 + \left(\frac{\partial A}{\partial Y}\right)^2 + \left(\frac{\partial A}{\partial z}\right)^2} \quad (2)$$

- Euler Deconvolution

The objective of the Euler deconvolution process is to produce a map showing the locations and the corresponding depth estimations of geologic sources of magnetic anomalies in a two-dimensional grid (Reid, *et al*., 1990).

Thompson (1982) showed that Euler's homogeneity relation could be written in the form

$$(x - x_o)\frac{\delta T}{\delta x} + (y - y_o)\frac{\delta T}{\delta y} + (z - z_o)\frac{\delta T}{\delta z} = N(B - T) \quad 1.3$$

Where (x_o, y_o, z_o) is the position of a magnetic source whose total field T is detected at (x,y,z). The total field has a regional value of B. The degree of homogeneity N may be interpreted as a structural index (SI) (Thompson, 1982), which is a measure of the rate of change with distance of a field.

4. Results and Interpretation

4.1 Total magnetic Intensity

The TMI map commences with a relatively medium susceptibility at the Northern end above Latitude 8°15', this makes up the region occupied by sand stones of the Nupe Basin where the sand stone lie on basement directly. Laterally lying below this is a region of relatively low susceptibility where susceptibility is between -66 and -114 nT. The low susceptibility might be due to thick overburden of erosional alluvium from the confluence of river Benue and Niger and the highly weathered migmatite and porphyritic granite. The middle of the study area around Lokoja exhibits the highest susceptibility where the old basement are quit exposed due to erosion. Worthy to note is a high susceptibility lithology around Latitude 7°15' at the lower part of the study area within the fika sandstone under which lies the lowest susceptibility which also comprise a region of high overburden due to erosion.

4.2 Result of Analytical signal

The Analytical analysis showed high amplitude of susceptibilities across the field, though majorly within the basement regions but some isolated structures were discovered to be located within the sediments such as that between Latitude 8°00' and 8°15' above and within Koton-karfe. Idah is on low amplitude while the granite below Lokoja depicts high amplitudes. High amplitude of susceptibilities ranges from 0.174 to 0.579 cycles (displayed in pink and red), while Medium and low amplitudes ranges from 0.021 to 0.157 cycles (displayed in yellow and green colours respectively).

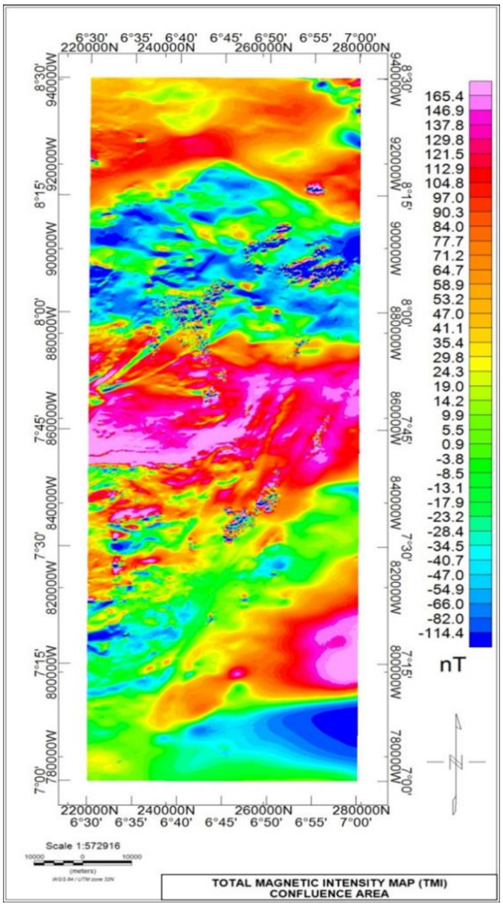

Figure 3: Total magnetic Intensity Map

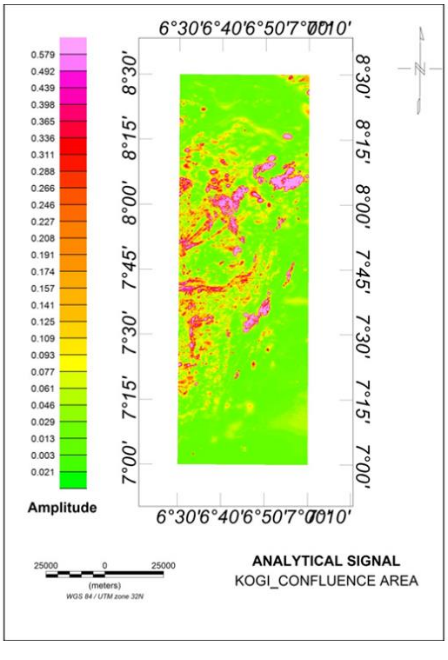

Figure 4: Analytical signal Map

4.3 Result of First Vertical Derivative (1VD)

The first vertical derivative map, Figure 5 displays magnetic structures that can be related to the geology of the area. The contact between the sedimentary formation of Nupe Basin and South-Western Basement complex is defined by set of folds around Latitude 8.15° cutting across the entire study area horizontally. Below this are sets of surface features B1 and B2 observed on the Total Magnetic Intensity (TMI) map just above Koton-karfe appearing as a mixture of both high and low susceptibilities, a clear feature of highly weathered basement structure. A similar surface feature B3 is captured at Adana (lower end of Lokoja) area overlaid by undifferentiated schist. Between Latitude 7.45° to 8.00° are sets of linear structures (F2 and F3) trending in the NE-SW direction. These sets of structures extend down to Koton-karfe area from Tajimi, Emu and Agbaja in the SW region of study area. The structures (lineaments) also define contacts between the Migmatite, the Porhyritic granite and the Banded Gneiss. A set of E-W trending linear structures F4 and F5 both of high and low susceptibility are situated on Latitude 7.40° at the Western part of the study area. These structures are located within the Migmatite and extending into the undifferentiated granite and into the Schist belt across the river Niger around Kuroko, Koji and Chita. The major (in length) lineament F6 in the study area is a diagonally NE-SW trending fault line taking off from the Limestone at Iyanipodi through shale at Adam and Egomicha into the undifferentiated Schist at Opada, Agbajo and Olowo.

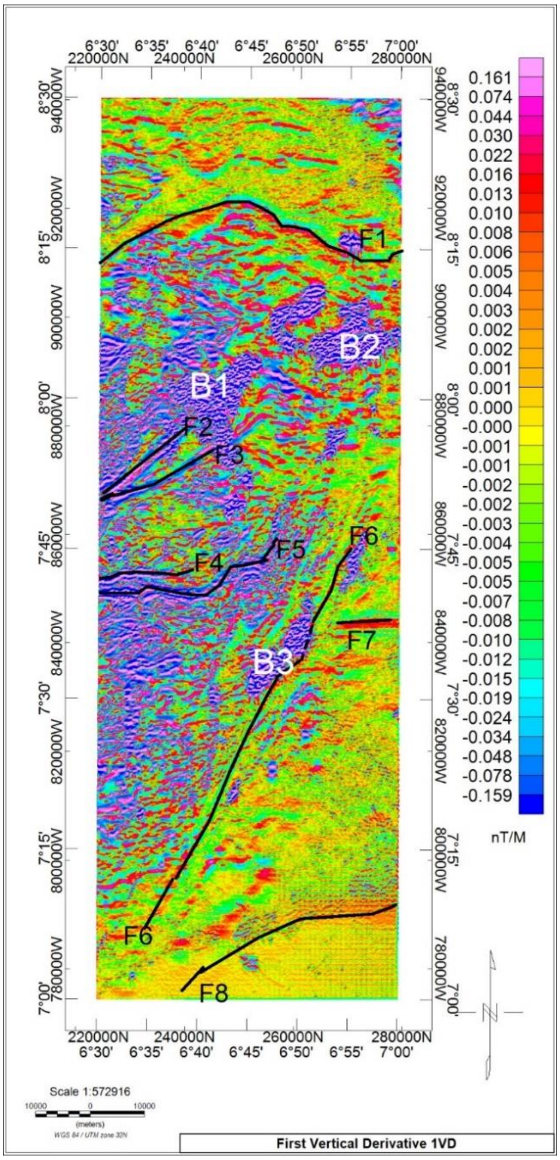

Figure 5: First Vertical Derivative Map (1VD)

4.4 Euler Deconvolution

The Euler depth map Figure 6 establishes the general distribution of depth to magnetic sources in the study area. The mapped depths are related to the lithological makeup of the various regions of study area. A moderate to deeper depth range of 670 to 1252 Metres was observed above and slightly below Latitude 8°00' lower end of Koton-karfe, this range agrees with that obtained by (Olaseinde *et al,* 2012) and is associated with several outcrops of the sandstones sections along the Lokoja - Abaji Road preserved by a hard indurate top layer of laterite (Akanmu, 1998). The basin geologies are covered by thick sediments hence the greatest depth to sources is observed in the sedimentary regions. Moderate to shallow depth to magnetic sources was observed around the basement regions as most of the basement rocks are situated as outcrops or at shallow depth below the surface.

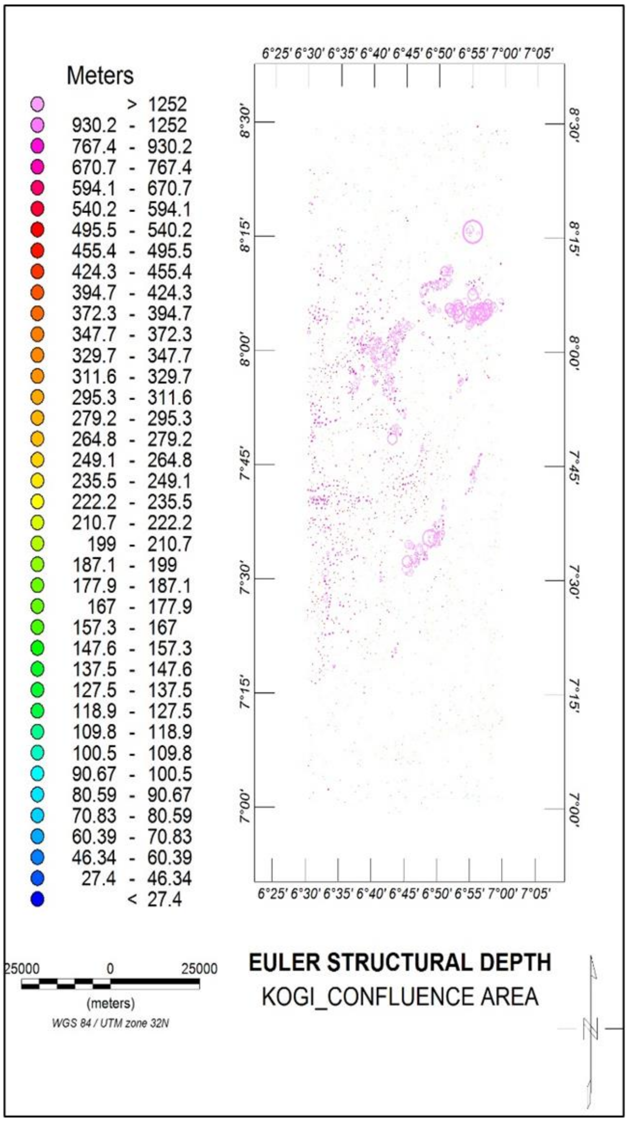

Figure 6: Euler Structural Depth Map

4.5 Potassium-Thorium Ratio map

Radiometric signatures from radioelement ratios are essential for detecting the enrichment or depletion of particular radioelement over the other. Mappings from radioelement ratios can proffer clear indications of hydrothermal alterations in rocks as it is a process that leads to the deposition and enrichment of one element at the expense of the other. (Schwarzer and Adams 1973). Due to the more mobile and soluble nature of K compared to Th, hydrothermal alteration processes usually leads to the enrichment and deposition of K-bearing minerals while Th is deficient from the components added to host rocks. (Hoover *et al*, 1992 and Portnov, 1987) gave the range of values for the K/Th ratio content of rocks that have not undergone alteration process to be between 0.17 %/ppm to 0.2 %/ppm. Anomalous values outside this range is attributed to K or Th specialised rocks (portnov, 1987). The K/Th ratio map Fig (7) shows clear indications of hydrothermally altered regions portrayed by values above stated threshold (0.2 %/ppm) shaded in pink colour. The regions around Latitude 8°00' and 7°30' within the NW and SW respectively mapped on the K/Th ratio map with colour shades of pink are areas that have undergone K enrichment due to hydrothermal alteration. The hydrothermally affected western regions of study area are characterised by felsic mineralized rocks such as; Migmatite, banded gneiss and porphyritic granite.

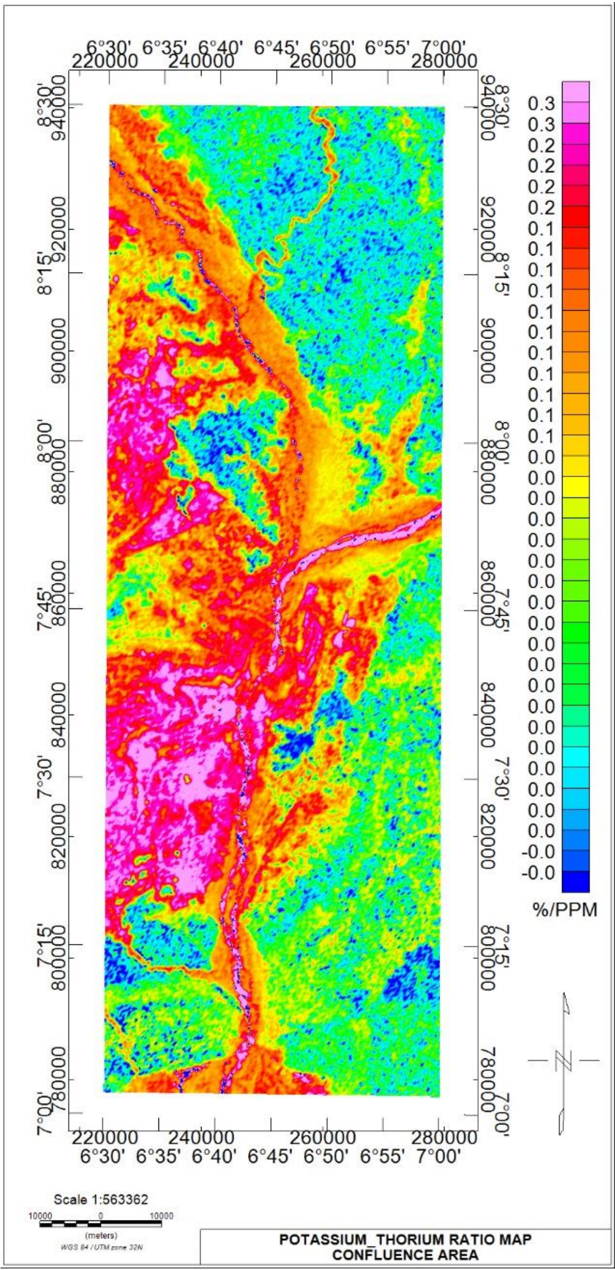

Figure 7: Potassium-Thorium Ratio map

4.6 Ternary Map

The Ternary image for the confluence area of Kogi state was computed using the RGB colour model and Histogram equalization colouring method. The image consists of colours produced from individual concentration of the gamma radiations corresponding to slight differences in the relative amounts of the components. Across the study area, regions with high concentration of the three radioactive elements (K, Th and U) are indicated as white while those in dark colours indicate low K, Th and U. Red is indicative of K dominance while Green and Blue colours indicates high Th and U respectively.

A clear blue colour dominating the North-Eastern corner of the study area is generally in the sedimentary region indicating high level of U and Th. This feature is associated with exposed iron stones gravel (Ramadas *et al,* 2013). Below the confluence of river Benue and Niger are regions of Brown to Dark Red colours, these are regions of granite and migmatite indicating high K and low concentration of Th and U. Observed on the western edge of study area at Latitude 7.45° is a bright green coloured feature which indicates relative high Th and U with low K, a feature that clearly indicates intrusion of granite into migmatite. The NW and SW regions coinciding with regions of migmatite and granitic rocks portrayed in dark red colouration are indicative of potassium feldspars presence (Ramadass *et al,* 2013). At latitude 8°00' is an enclosed blue-green colour denoting and intrusion of feldspathic sand stones into the migmatite terrain, an area also observed as weathered basement on the TMI map showing mixture of high and low susceptibility.

Worthy to note on the ternary image are two giant strips of blue and dark colouration extending from the Eastern edge and curving in the south. The blue strip significantly indicates a contact between the encroaching Anambra basin in the South-East and the basement geology in the Western part of study area. The blue strip is also associated with ironstone and sandstone as indicated on the geology map. The dark strip is a clear reflection of fluvial lithology in the sedimentary basin characterised by fika sandstone and clay as indicated by geology map. The dark strip also correlates to low concentration of the three radioelements which is attributed to varying geologic framework compositions, weathered materials or fluids formed as a result of intense metamorphism. (Ademila *et al*, 2018). The river channel running from the North through to the South is depicted in dark colour reflecting low concentration of the three radiogenic elements. The low concentration along the water body is attributed to the fact that water bodies shield all radiations (Graham, 2013)

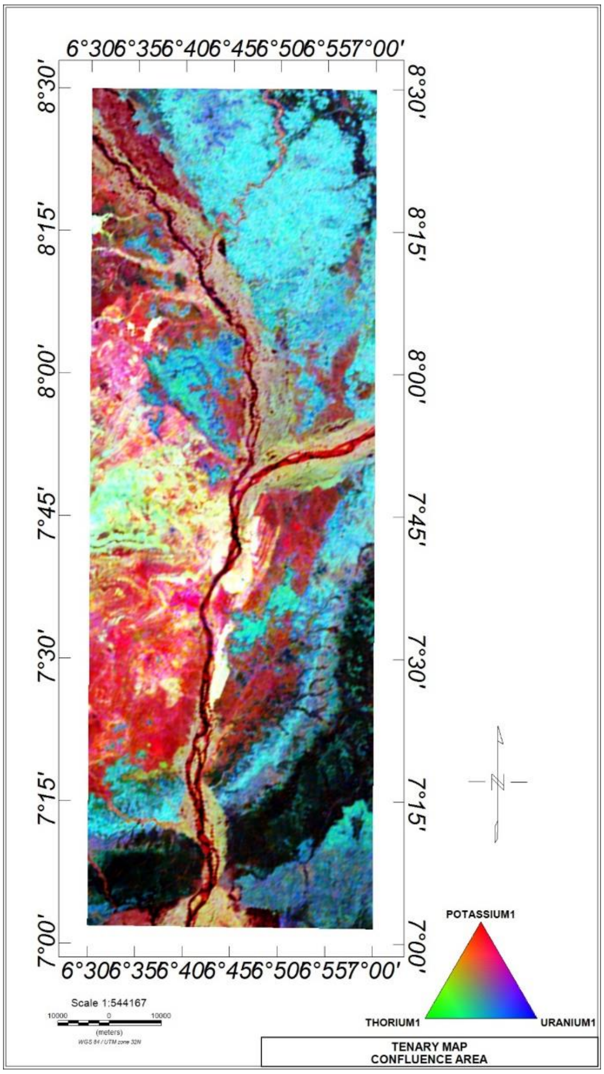

Figure 8: Ternary Map of study area

5. Results Discussion

The TMI showed regions with negative and positive magnetic susceptibility that relates to the geological setup of the study area. The Analytical Signal showcased amplitude response that corresponds to magnetic susceptibility of the study area. The Vertical derivatives revealed folds, fault line and potent mineral lineaments labelled F1 to F8. Also three cringing surface features (B1, B2 and B3) exhibiting mixture of negative and positive magnetic susceptibilities corresponding to an intrusion of oolitic iron ore within the sedimentary formation. The longest lineament F6 is a fault line running diagonally from Eastern edge to South-Western lower end of study area along the coast of the river Niger. The Euler depth and structural map revealed the depth to magnetic bodies of interest. A depth range of 27 to 1252 Metres were recorded as minimum and maximum depth to magnetic sources respectively across the study area. Worthy to note is the high depth range of 670 to 1252 meters at the lower end of Koton-karfe. This depth range agrees with that obtained by (Olaseinde *et al,* 2012). Major bands of lineaments in the study area were mapped trending NE-SW and E-W, a trend that was also observed by (Adetona and Abu Mallam 2013). The contacts between geological formations were also seen as a fold (F1) at the middle portion of koton-Karfe where the southern Nupe/Bida basin terminated at the edge of Western Nigeria basement. Also F8 is another fold in the South-east where part of Anambra Basin encroached into study area.

6. Conclusion

The interpretation of Aeromagnetic and Radiometric data of the confluence area of Kogi state gave insight to useful geological deductions. Analysis of the airborne geophysical data set provided structural and lithological details of the basement and sedimentary geologies construed in the study area. The western region of study area is generally an extraction of the most mineralised western region of Kogi state, it is also the basement region of study area where most of the mineralised features were delineated. Deductions from the 1VD map shows major Structures in form of magnetic lineaments that can be related to iron ore formations in the study area traced at Agbaja, Emu, Tajimi and Koton-karfe (Fatoye 2018). Ternary and K/Th ratio maps both revealed the western regions to be rich in K-Feldspar minerals and also host hydrothermally altered zones. The zones of alteration also corresponds to the areas delineated to host major magnetic lineaments of mineral potential trending NE-SW and E-W direction of study area. This makes the NW and SW regions of study area hosting major lineaments and zones of hydrothermal alterations the best target for exploration of iron ore and K-feldspar related minerals such as gemstones (Fatoye 2018). Essential minerals such as gold could also be a target for exploration in the western region of study area as potential gold deposits often occur in the hydrothermal altered zones rich in potassium (Ohioma et al. 2017). The sedimentary basins were delineated to host majorly sediments in the form of sandstone, shale, limestone, mudstone, coal, clay and alluvium.

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