ANALYSIS OF AEROMAGNETIC DATA FOR COAL DEPOSIT POTENTIAL OVER BIRNIN KEBBI AND ITS ENVIRONS, NORTHWESTERN NIGERIA

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This study employed magnetic signatures alongside field geological techniques in characterizing the structures that may host coal deposit around the study area. The interpretation of the data extracted from the aeromagnetic maps of the basin was carried out using automated techniques involving regional-residual separation, reduction to the pole RTP, analytic signal, first vertical derivative and second vertical derivative. Results from analytic signal technique showed that the sedimentary basin in the study area is associated with different rock types and occurrence of geological features to revealed the existence of coal in the study area. This has indicated that the site labelled Zone A has the potential for coal deposit due to the local redox states of sediments in the regions that are controlled by carbonate content of the depositional environment. The region labelled Zone A consists of locations such as Birnin Kebbi, Kalgo and part of Suru Local government areas. These regions have magnetic susceptibility values coinciding with that of the Coal (carbonaceous sedimentary rock) under the positions of 12°10′0″N to 12°30′0″N and 4°5′0″E to 4°15′0″E (Birnin Kebbi LGA), 12°20′0″N to 12°28′0″N and 4°0′0″E to 4°3′0″E (Kalgo LGA) and 12°0′0″N to 12°5′0″N (part of Suru LGA).

Key word: Coal, aeromagnetic data, Birnin-Kebbi, analytical-signal and residual.

INTRODUCTION

Coal is a carbonaceous sedimentary rock formed from organic matter and contains carbon and other elements, such as hydrogen, oxygen and nitrogen (NMA, 2000). It is the most valuable organic resource in Nigeria and the world at large. It is the main energy carrier for thermal power plants, local boiler houses and other industrial activities (Narimi et al., 2019). Coal was the source of power generation in Nigeria as well as the main source of energy for the railway transportation systems between 1895 and 1962; hence it has contributed immensely to the economy of Nigeria (Jargalmaa et al., 2015).

Distribution of the solid mineral particularly coal has been found across the country in areas such as: Adamawa, Akwa Ibom, Bauchi, Benue, Cross River, Enugu and Gombe states (Olalekan et al., 2016). The coal is more evenly distributed worldwide and often readily accessible by open-cast mining. Owing to instability of the world oil market, the diversification of energy carriers is practically implemented in many countries with involvement of various non-traditional types of organic raw materials (such as coal) whose reserves are greater than oil and gas reserves (Adewumi and Salako, 2018).

In this study, aeromagnetic method was used because it covers large-scale magnetic surveys, using magnetometers attached to or suspended from aircraft. In regions of subdued magnetic character (that is sedimentary basin), contrasts in magnetic susceptibility of both paramagnetic and diamagnetic minerals can be detected. Typical aeromagnetic surveys measure magnetic responses associated with particular iron-bearing minerals (ferromagnetic). The method is one of the most reliable, cost-effective and fastest means of covering large area, even with rough terrain. It also measures the variations in the earth magnetic field produced due to the induced and remnant magnetization between the host rock and the mineralized bodies (Ejepu et al., 2018). The strength of magnetization in rock is related to the local intensity of the earth's field as given in Equation 1.

$$M = k\mathrm{H} \qquad (1)$$

where M is the magnetisation per unit volume, k is the magnetic susceptibility (for the volumetric unit) and H is the local intensity of the earth's magnetic field.

LOCATION AND GEOLOGICAL SETTINGS OF THE STUDY AREA

This study covers Birnin Kebbi local government area and its' environ, including: Aleiro, Bunza, Gwandu, Jega, Kalgo, Maiyama and Suru areas of Kebbi State, Nigeria. The study areas cover an area of approximately 3025 km^2 in the North-Western part of Nigeria and lies between latitudes 12°0′0″N and 12°30′0″N, and longitudes 4°0′0″E and 4°30′0″E (Figure 1). Kebbi state falls within the Sokoto basin which is part of an extensive elongated sedimentary basin underlying most of the North-western Nigeria and eastern part of Niger Republic (Augie et al., 2019). Geologically, the study area falls under the Sokoto basin which is divided into two groups, Sokoto group and Rima group. The later consist of Dukamaje Formation, Kalambaina Formation, Taloka Formation, Illo Formation and Gundumi Formation, while the former group consists of Gwandu formation, Dange Formation and Wurno Formation (Augie et al., 2019). Study area falls within the Gwandu and Taloka formation that comprises sandstones, limestones, laterite, siltstones,

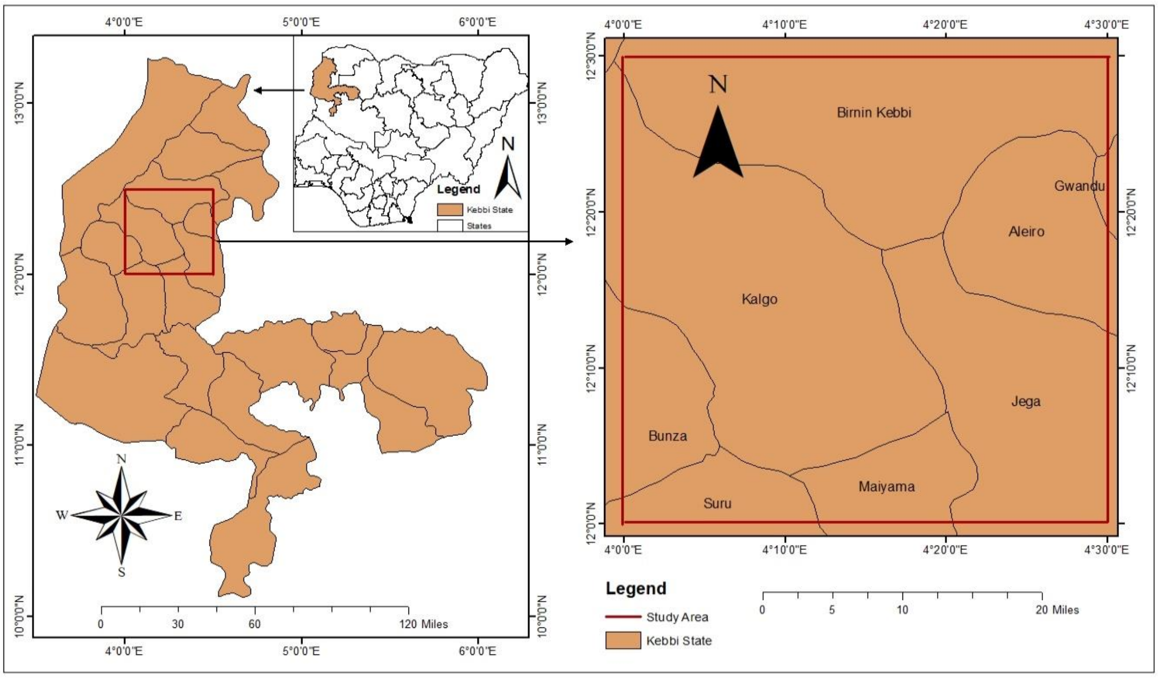

Figure 1. Location map of the study area.

metaconglomerates, shales and clay (Figure 2). These formations (Eocene-Miocene) are one of the formations in Sokoto Basin. The sediments comprise massive clay interbedded with sandstone (Augie et al., 2019).

METHODOLOGY

Nigeria Geological Survey Agency (NGSA) carried out geophysical surveys covering all part of the country in collaboration with the Fugro airborne surveys between 2006 and 2007. In this study, sheet number 49 was used covering Birnin Kebbi and its environs of sedimentary basin. The flight parameters of the aeromagnetic data are: Flight line spacing (500 m), Tie line spacing (2000 m), Terrain clearance (80 m), Flight direction is NW-SE and the Tie line direction is

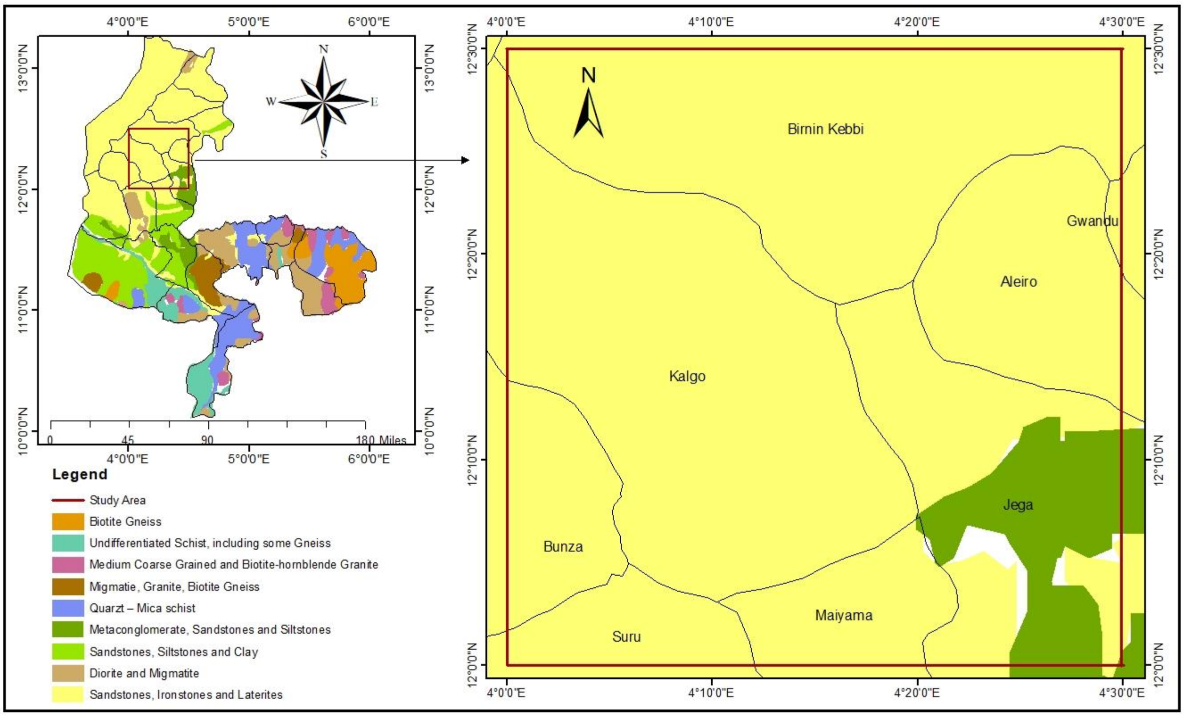

Figure 2. Geological map of the study area.

NE-SW. The survey involved the acquisition of the magnetic dataset. The acquisition of the magnetic dataset involves the attachment of the 3 ×3 Scintrex CS3 cesium vapour magnetometer sensor on a fixed wing of the aircraft. The acquired parameters were stored, the raw magnetic susceptibility values and the aircraft variations were corrected for both the diurnal variation and the International Geomagnetic Reference Field (IGRF). The acquired corrected aeromagnetic dataset was subjected to the Bi-directional gridding method to produce the Total Magnetic Intensity (TMI) anomaly grid.

Data processing

The aeromagnetic data was further processed, enhanced and interpreted with Geosoft (Oasis Montaj) and Surfer. In this study, different processing techniques were employed to enhance the magnetic data which include: regional-residual separation, reduction to the pole RTP, analytic signal, first vertical derivative and second vertical derivative (Figure 3).

Regional-residual separation

This technique was employed by processing The Total Magnetic Field Intensity (TMI) value acquired from NGSA was stripped of 33,000 nT in order to mitigate weight of data in their database, therefore 33,000 nT was added to each value of the TMI to obtain the actual TMI. This total magnetic field comprises the effects of all magnetic sources (Ologe, 2019). The targets of this research are relatively small, shallow depths anomalies, and their magnetic field is super imposed on the regional field that comes from larger or deeper sources. The residual field was obtained by removing the regional field as a first order polynomial (that is using polynomial regression technique) from the TMI using a grid cell size of 150 m.

Reduction to the pole

The method was adopted to alter the data so that peaks lie directly over causative bodies, which usually does not work well in lower latitudes where the magnetic field lies at a shallow angle to the Earth’s surface. The region of low latitude, magnetic field usually produced by magnetized rocks and is too difficult to interpret (Sani et al., 2019). For reasons, the technique was adopted to produces anomalies vertically over their respective causatives sources. The total magnetic intensity grid was applied for reduction to the

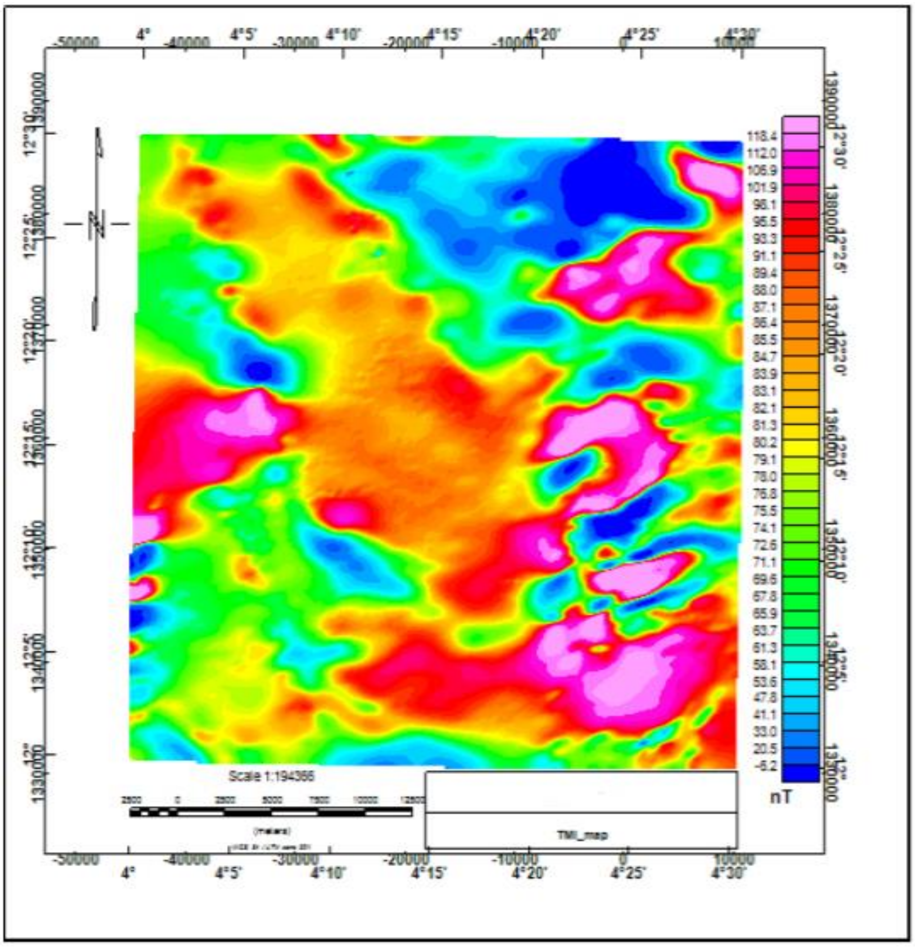

Figure 3. Total magnetic intensity map (TMI).

pole; this operation changed the actual inclination to vertical. Reduction to the pole is the process of converting the magnetic field developed by magnetic bodies from the magnetic latitude where the Earth's field is inclined, to the field at the Earth's magnetic pole, where the inducing field is vertical. A basic assumption of the reduction to the pole process is that all bodies are magnetized by induction.

First and second vertical derivatives (FSD and SVD)

These techniques were adopted in this study to quantify the spatial rate of change of the magnetic field in horizontal or vertical directions. Derivatives essentially enhance high frequency anomalies (that is shallow features) relative to low frequencies anomalies (that is deep features) and sharpen the edges of anomalies. Vertical derivatives are a measure of curvature, and large curvatures are associated with shallow anomalies. Thus, it enhances near-surface features at the expense of deeper anomalies.

The first vertical derivative, FVD (Figure 4) reveals more of the subsurface structures and the second vertical derivative, SVD analysis provides a means of discriminating local features, while suppressing broad and regional structures. SVD has a better resolving power than the first vertical derivative (Figure 5) and derivative maps can therefore be used or has been used to sharpen the edges of magnetic anomalies and to better their locations.

The first and second vertical derivatives are given as:

$$FVD = \frac{\partial M}{\partial z}\ ,\ SVD = \frac{\partial^2 M}{\partial z^2} \qquad (2)$$

where M is the potential field anomaly. In this study, the residual field data obtained by removal of regional field from TMI itself due to some

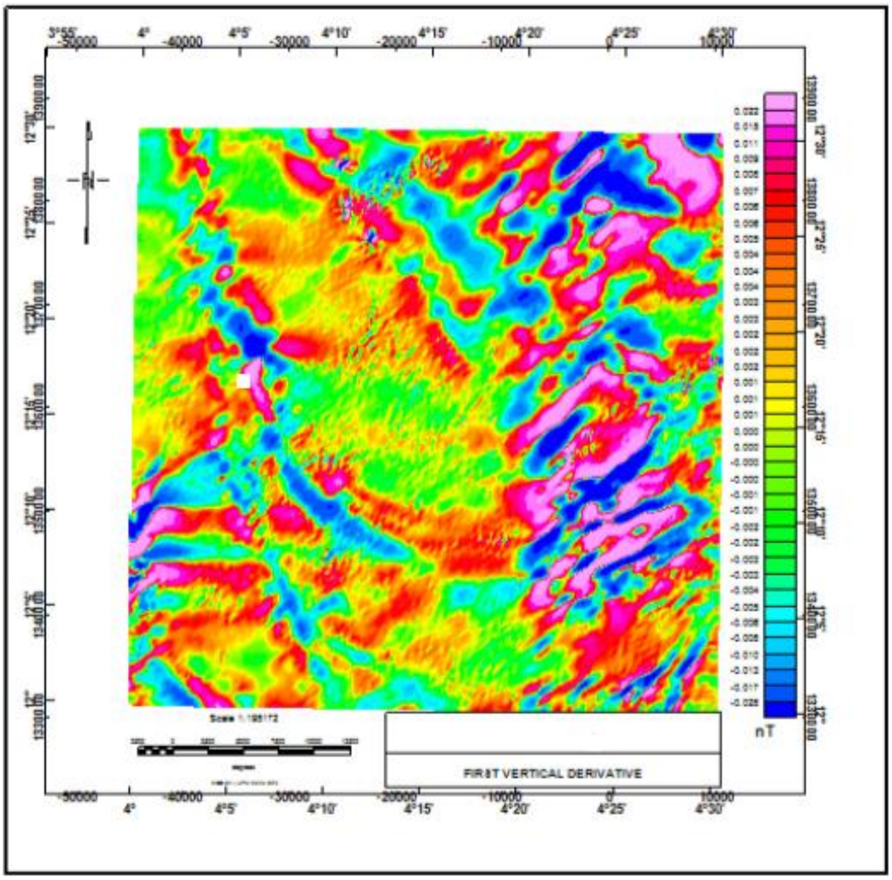

Figure 4. First vertical derivative map.

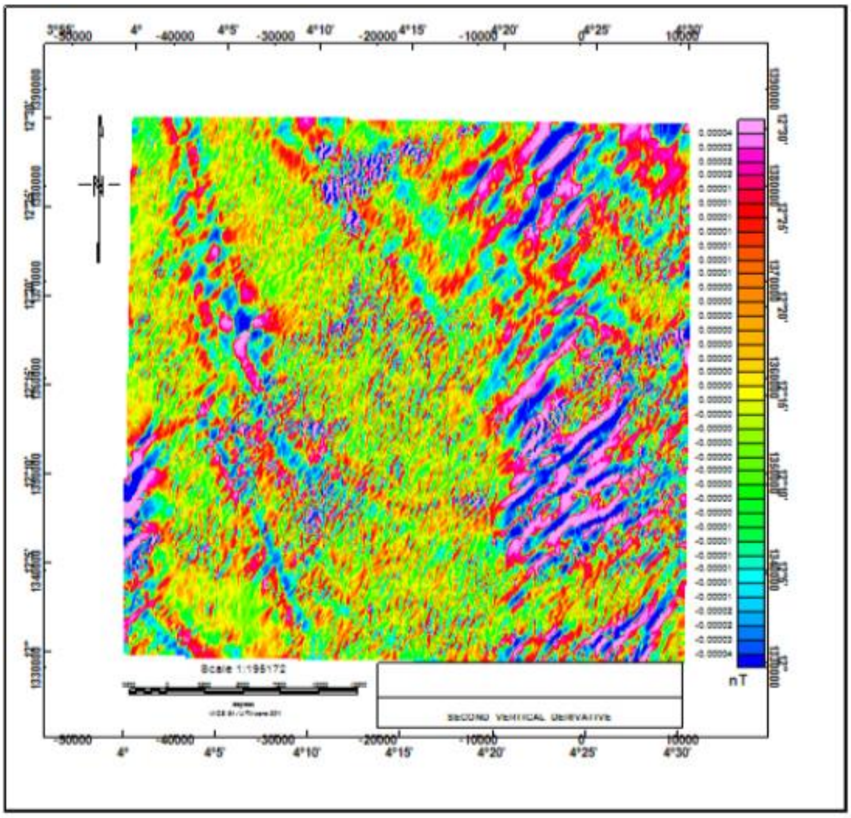

Figure 5. Second vertical derivative map.

noise arises from cultural features such as electric pole, metallic objects, buried pipes etc. These noises were filtered through upward continuation to obtain the filtered residual field data. The second vertical derivative was then applied on the filtered residual field data (that is the upward continued field data) to enhance the near surface structures of interest.

Analytical signal (AS)

The analytic signal technique is based on the use of the first derivative of magnetic anomalies to estimate source characteristics and to locate positions of near surface geologic features (Figure 6). The AS method is unlike the reduction to equator (RTE), that does not require the direction of magnetization source prior to the application of the filter. The AS filter is defined as the square root of the sum of the vertical and horizontal derivatives of magnetic field given as thus:

$$A(x,y) = \sqrt{\left(\frac{\partial T}{\partial x}\right)^2 + \left(\frac{\partial T}{\partial y}\right)^2 + \left(\frac{\partial T}{\partial z}\right)^2} \quad (3)$$

where, the first derivatives $\frac{\partial T}{\partial x}, \frac{\partial T}{\partial y}$ and $\frac{\partial T}{\partial z}$ of the total magnetic field and x, y and z are the directions and A (x, y) is the amplitude of the analytic signal at (x, y); T is the observed magnetic field at (x, y). The purpose of the reduction to the pole is to take an observed total magnetic field map and produce a magnetic map result for an area surveyed at the magnetic pole.

RESULTS AND DISCUSSION

Figures 3, 4, 5 and 6 were the results from different processing techniques that were employed in enhancing the magnetic data which includes: regional-residual separation, reduction to the pole (RTP), analytic signal, first vertical derivative and second vertical derivative. Sediments usually shows the widest variation in Fe content of all common rock groups with approximately 0% within an orthoquartzite to 70% with outcrop scale, massive magnetite-haematite layers of primary banded iron formation. Different kind of sediments therefore has variations in susceptibility k, as shown below. The magnetic susceptibility values of some common rocks include the sedimentary rocks given in Figure 7.

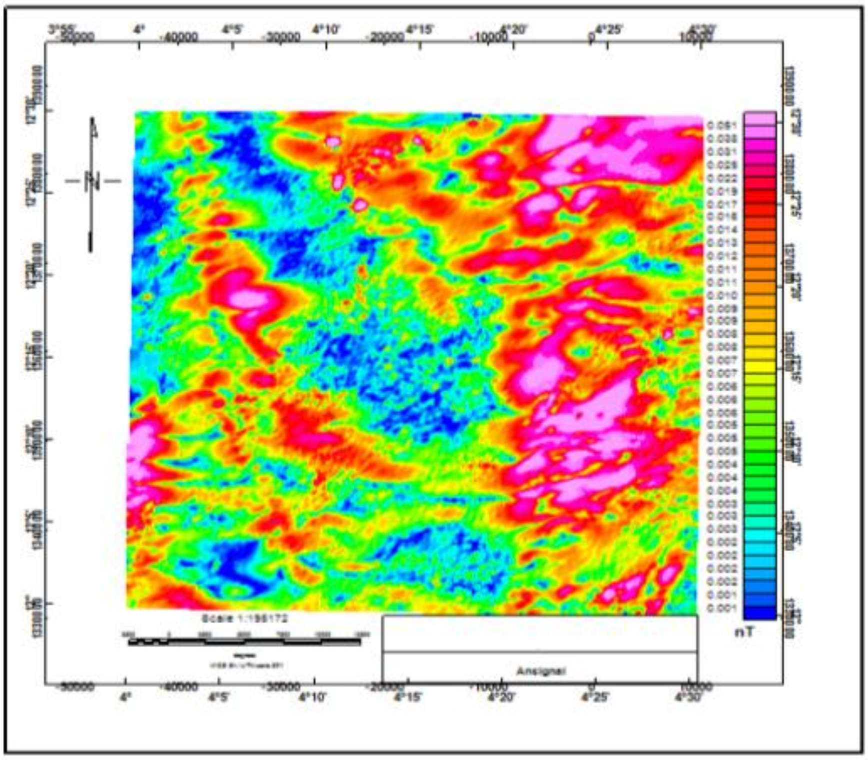

Figure 6. Analytical signal map.

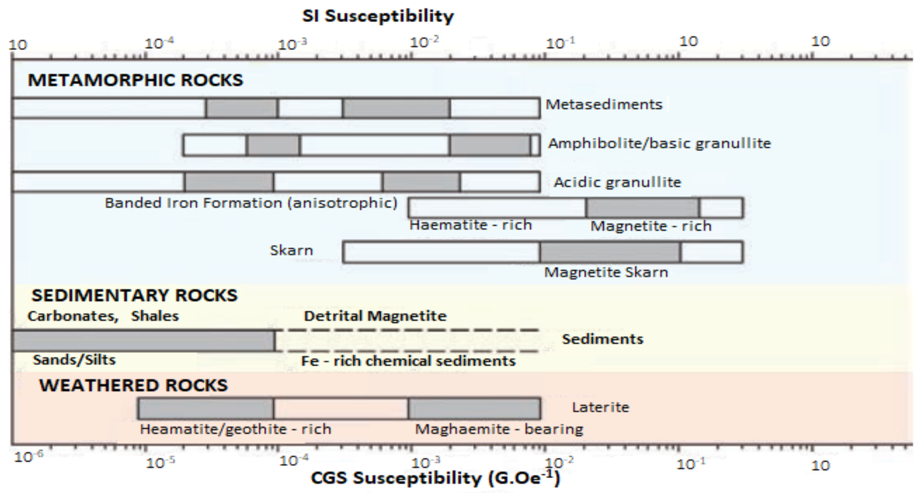

Figure 7. Common magnetic susceptibility ranges for various rocks types (Clark, 2010).

The contoured map of the anomaly (Figure 8) was used in the qualitative interpretation instead of the original (TMI) anomaly map, because it provides direct evidence of the existence of the reservoir type structures or mineral bodies. The result presented in Fig. 8 indicate that the study area is made of 4 magnetic zones, each having a unique magnetic anomaly pattern/or values and these values were compared in Figure 7. Observing the maps (Figure 8) closely under positions of 12°10′0″N to 12°30′0″N and 4°5′0″E to 4°15′0″E (Birnin Kebbi LGA), 12°20′0″N to 12°28′0″N and 4°0′0″E to $4^{0}3'0''$E (Kalgo LGA) and $12^{0}0'0''$N to $12^{0}5'0''$N (part of Suru LGA) the zone was named as Zone A. When these magnetic values are considered in relation to Figure 7 it is observed that the regions have susceptibility values coinciding with that of the carbonaceous sedimentary rock (Coal). The local redox states of sediments in Zone A are strongly controlled by carbonate content of the depositional environment and also the carbonates species are usually strongly dependent on both sedimentary facies and sediment provenance.

Zones B and C are magnetite and pyrrhotite

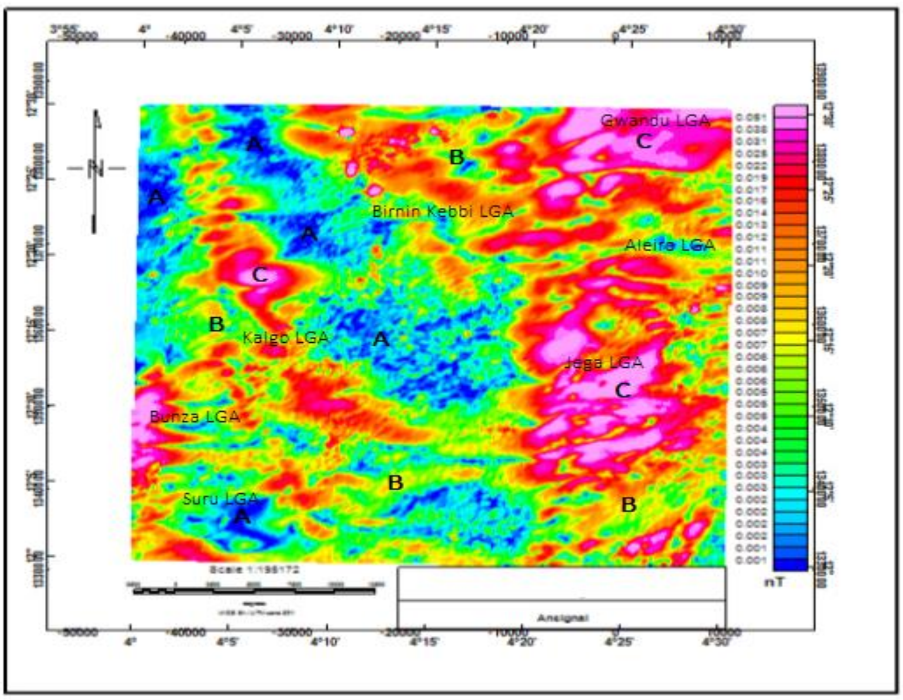

Figure 8. Analytical signal map showing anomaly of interest.

minerals with moderate susceptibilities k (Figure 7), and are both typical metastable in low T/low P, high fO_2 conditions; that is the condition prevailing in the post early palaeoproterozoic sedimentary rock – forming environment. Fe-bearing minerals initially formed in these zones as sediments are generally dominated by haematite (Fe_2O_3), Siderite (Fe_2CO_3), pyrite (FeS_2) and various hydrous oxides. Zone D is characterized by high magnetic anomalies, comprising incorporation of detrital magnetite grains sourced from pre-existing basement rocks. The magnetite grain will survive significant transport and hydrous activity because magnetite is metastable rather than unstable in near surface conditions. These anomalies, lies on the positions of 12°26′0″N to 12°30′0″N and 4°21′0″E to 4°30′0″E (Gwandu), 12°7′0″N to 12°15′0″N and 4°20′0″E to 4°27′0″E (Jega), 12°16′0″N to 12°21′0″N and 4°4′0″E to 4°7′0″E (part of Kalgo). This region distributes the stability of crystallization of Fe bearing mineral spaces (mafic and ultramafic rocks contain Fe) and also highlights the trend of crystallization towards increasingly oxidized Fe mineral from the mafic to felsic rock. Zone B indicates Fe with intermediate to felsic rocks that is increasingly partitioned into more oxidized mineral (trending from titanomagnetite – magnetite – ilmenite - haematite).

Conclusion

The study has revealed the rock types and occurrence of geological features that revealed the existence of coal in the study area. The result has indicated that the sites having potential for coal deposit are Zones A due to the local redox states of sediments in the regions that are controlled by carbonate content of the depositional environment. Zone A of coal deposit potential occupied areas such as: Birnin Kebbi, Kalgo and part of Suru LGAs.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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