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EXPLORATION FOR COAL DEPOSIT IN THE NORTH EASTERN PART OF SOKOTO BASIN, NIGERIA USING AEROMAGNETIC DATA

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Abstract

Preliminary exploration obtained from mechanized dug wells has found traces of coal mineral within Dukanmaje Formation, Gada Local Government Area of Sokoto State. This warrant the present geophysical investigation aimed at ascertaining the possible coal reserve in Dukanmaje Formation. Aeromagnetic Data acquired from the Nigerian Geological Survey Agency (NGSA) were processed and analyzed using Oasis Montaj version 6.4.2 and Surfer Version 12 softwares respectively. The geologic features of coal in the study area, were deduced from the analysis and interpretation of aeromagnetic data Sheets (3, 4, 10 and 11). Result from the interpretation indicates Gada, (13˚44ˈN, 5˚37ˈE); Dukanmaje (13˚43ˈN, 5˚52ˈE); Kwakwazo (13˚34ˈN, 5˚37ˈE); Kaddi (13˚38ˈN, 5˚45ˈE); KyadawaHolai (13˚44ˈN, 5˚29ˈE); as the potential sites for detail geophysical exploration of coal due to their very low magnetic susceptibility values (highly negative) and long-wavelength magnetic anomalies that are smooth over considerable distances with traces of coal in the near surface areas. Residual contour map indicates that, Dukanmajeformation, has a total area of 370.290649 Km^2.

Keywords: Aeromagnetic, Coal, Exploration

1. Introduction

Coal is one of the world's most important sources of energy worldwide. Some countries like Poland, South Africa, China and Australia relies on coal for over 94%,92%, 77% and 76% respectively in the production of electricity. Coal has played this important role for centuries not only providing electricity, but also an essential fuel for steel and cement production, and other industrial activities. The abundance nature of this mineral in some part of the world makes it to be one of the world most important sources of nonrenewable energy [1].

There are about seven basins in Nigeria, being suspected of having either hydrocarbon potentials or hydrocarbon reserve and Sokoto basin is one of them. Other economic minerals such as gypsum, coal and limestone can also be found in the basin. However, the petroleum potential of the trough attracted great interest to geologists and geophysicists neglecting other economic minerals in the basin such as coal. [2]. This study therefore aims at ascertaining the possible coal reserve in Dukanmaje Formation and map out potential sites for detail geophysical exploration of coal in the area using aeromagnetic geophysical method.

Aeromagnetic geophysical method is the fastest among other geophysical methods and low cost per unit area explored. These features distinguish it compared with other geophysical methods since its inception [3]. This means geophysicists can acquire data regardless of ownership or accessibility of remote lands of interest. The inherent advantage of aeromagnetic method for large scale airborne cannot be overemphasized; survey can be carried out around the globe in a small period. The interpretation of the total aeromagnetic map of some part of the Basin will aid evaluation of the coal reserve in the area.

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The origin of the magnetic field in Aeromagnetic geophysical method is from the molten metal core which envelope the earth. Many geological structures and formations have their own magnetic field constituents, which interact with the earth magnetic field resulting to the formation of the magnetic field of the anomaly[4].The effect of the magnetic field anomalies can be smaller than the local field or larger than the local field, thus, it may either be added or subtracted from the Earth's local magnetic field. The size and shape of the anomalies depend on the geometry and depth of the anomalous structure, the degree of magnetisation and the direction of the magnetisation with respect to the Earth's magnetic field [5]. This means analysis of local magnetic fields on the surface earth can indicate the presence of underground coal deposits or mineral associated with it [4].

1.1 General Magnetic Field of the Anomaly

Potential equation within the regions occupied by the magnetic scalar potential is due to continuous distribution of matter; for example, earth may be calculated at an external point. If the material that fills the volume V, has a continuous distribution of magnetic dipole per unit volume, then,

$$J = M/V \qquad (1)$$

The magnetic potential A of a dipole at point P, outside the volume V, with moment M, is given by

$$A = \frac{M\cos\theta}{r^2} - M.\nabla\frac{1}{r} \qquad (2)$$

The potential equation within regions occupied by magnetic bodies is given by Equation (3). Magnetic properties of different types of soil display different aspect of soil mineralogy. [6].

$$\nabla.A = -4\pi\nabla.J \qquad (3)$$

1.2 Location of the Study Area

The study area lies in the northwestern part of Nigeria (Figure 1). It is bounded by Latitude 10^{o} 30″ N to 14^{o} 00″ N and longitude 3^{o}30″ E to 7^{o} 00″ E with an estimated area of 59,570 km^2.Sokoto Basin is a sedimentary basin with gentle undulating plain varying from 250 to 400 meters above sea level. The basin forms the south-eastern sector of the large nearly circular sedimentary basin, generally referred to as the Iullemmeden Basin of West Africa [7].

1.3 Geology of the Study Area

Raider in 1931 described the term Iullemmeden Basin, as a sedimentary basin, which extend from Mali and the western boundary of the republic of Niger through northern Benin Republic and north-western Nigeria into eastern Niger and covers an area of about 800,000 m^2[8].

The most important economic mineral deposits in the "lower Sokoto basin" are the industrial minerals consisting of clays, ironstone and laterites including liquate radioactive minerals and salts.

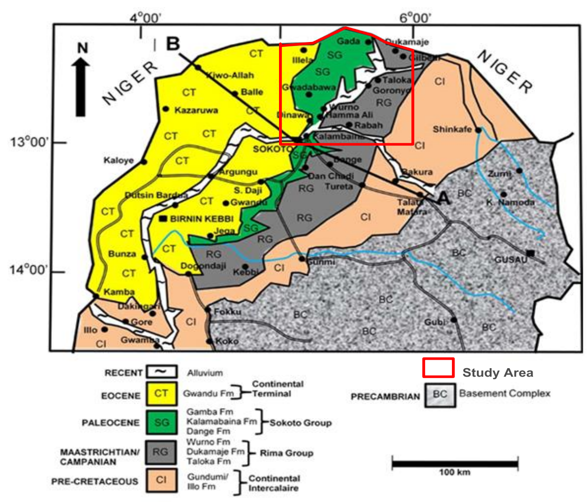

Figure 1: Generailized geological map of the nigerian sector of illumendin basin (sokoto basin) showing the study area[9].

2. Materials and Method

2.1 Acquisition of Data

The study area consists of sheets number (3, 4, 10 &11) of Sokoto sedimentary basin. Aeromagnetic map used in this study was acquired from the Nigerian Geological Survey Agency (NGSA), which was the recent aeromagnetic data acquisition and compilation in the country by Fugro Airborne Surveys, carried out between 07/12/06 - 31/05/07. To achieve this, the Nigerian landmass was divided into several blocks. These blocks were further divided into approximately three hundred and twenty-three sheets (323). The magnetic data were collected at a normal flight altitude of 100m along N-S and flight lines spacing of 500m at a speed approximately 2km apart. The data were then published in the form of half degree by half degree (½˚ by ½˚) aeromagnetic map on a scale of 1:100,000. The magnetic values were plotted at 10nT interval**.** The maps are numbered, and names of places and coordinates (longitude and latitudes) written for easy reference and identification. The actual magnetic values were reduced by 33000nT before plotting the contour map. This implies that the value 33000nT is to be added to the contour values so as to obtain the actual magnetic field at a given point. The visual interpolation method that is the method of digitizing on Grid Layout was used to obtain the data from field intensity aeromagnetic maps covering the study area [10].

2.2 Production of TMI map
Oasis Montajwas used to produce Total Magnetic Intensity map (TMI). The software is an interactive computer program which places magnetic data according to their longitude and latitude bearing and gives a magnetic intensity map in color aggregate.

2.3 Regional-residual Separation
Magnetic data observed in geophysical surveys comprises of the sum of all magnetic fields produced by all underground sources. The composite map produced using such data, therefore contains two important disturbances, which are different in order of sizes and generally super-imposed. The large features generally show up as trends, which continue smoothly over a considerable distance. These trends are known as regional trends. Residual anomalies area Super-imposed on the regional field, but frequently camouflaged by smaller local disturbances which are secondary in size but primary in importance. They may provide direct evidence of the existence of the reservoir type structures or mineral ore bodies.

2.4 Qualitative Interpretation
This involves the description of the survey results and the explanation of the major features revealed by a survey in terms of the types of likely geological formations and structures that gave rise to the evident anomalies. Typically, some geological information is available from outcrop evidence within the survey area (or nearby) and very often the role of the geophysicist is to extend this geological knowledge into areas where there is no outcrop information (i.e. extrapolation from the known to the unknown) or to extend mapped units into the depth dimension (i.e. to help add the third dimension to the mapped geology). General inferences can be made from magnetic anomaly shapes.
For example, consider Figure 2 below, anomaly B has the same form as anomaly A, but anomaly B has longer wavelength than anomaly A, therefore anomaly B is deeper in magnetization than anomaly A.

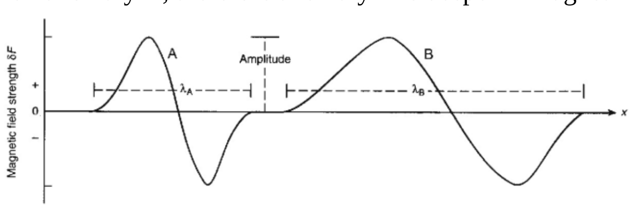

Figure. 2: Example of magnetic anomaly signature and amplitude variation. [4]
Since the amplitude B is greater than amplitude A, B will have deeper penetration than A.

3. INTERPRETATIONS OF RESULT AND DISCUSSION
Geological and geophysical interpretation constitutes one of the important tasks in the process of analysis of the aeromagnetic map. Aeromagnetic maps in particular can be used to identify both shallow and deep geological structures. This research is going to focus on swallow geological structures in the north eastern part of Sokoto Basin. Quantitative interpretation is based on the analysis of transformed magnetic maps using a range of filters. Derivative or gradient maps are often used to enhance short wavelength anomalies related with shallow sources [11].

3.1 The Total Magnetic Intensity (TMI) Map of the Study Area
The magnetic intensity values of the study area ranges from 32970.0 nT (minimum) to 33110.6.8 nT (maximum). The TMI of the study area as shown in Figure 3 can be divided into three main sections. The pink to red color which indicate high magnetic intensity values, yellow-orange color which is characterized by medium magnetic intensity values and green-blue color which signifies low magnetic intensity and though minor depressions exist scattered all over area. The high magnetic intensity values dominating the southern part of the study area, are caused probably by near surface igneous rocks intrusion.

While the medium and low values of magnetic susceptibility dominating the northern part of study area are most likely due to sedimentary rocks and other nonmagnetic mineral such as coal, water, salt etc. High amplitudes and high wave number existing in both northern and southern part of the study area also probably an indication of thedepth of sedimentary thickness and near basement complex. In general, high magnetic values arise from igneous and crystalline basement rocks. Whereas low magnetic values are usually from sedimentary rocks or altered basement rocks. The sedimentary thickness of some part of the study area in general, appears to increases from south to north. The north east part of the TMI show a lot of activities, as they are dotted by the mixtures of both high and low magnetic signatures which characterized surface to near sub surface features and out crops.

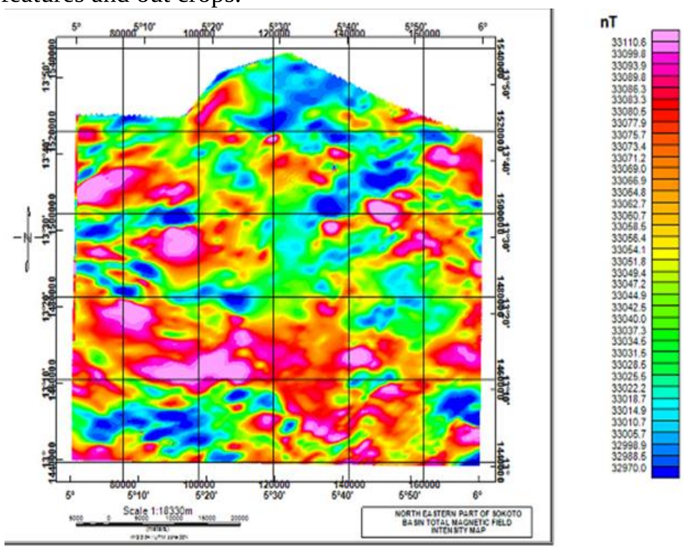

Figure 3: Total magnetic intensity map of north eastern part of Sokoto basin

3.2 Regional Magnetic Intensity Map

The regional magnetic values depicted in Figure 4 ranges from 33037 nT to 33060 nT and the values increase from south to north indicating there is a fill of sediments in the southern part of the area than in the northern part of the study area. The result of regional indicates deeper sedimentation in the north, than in the southern part of the study area.

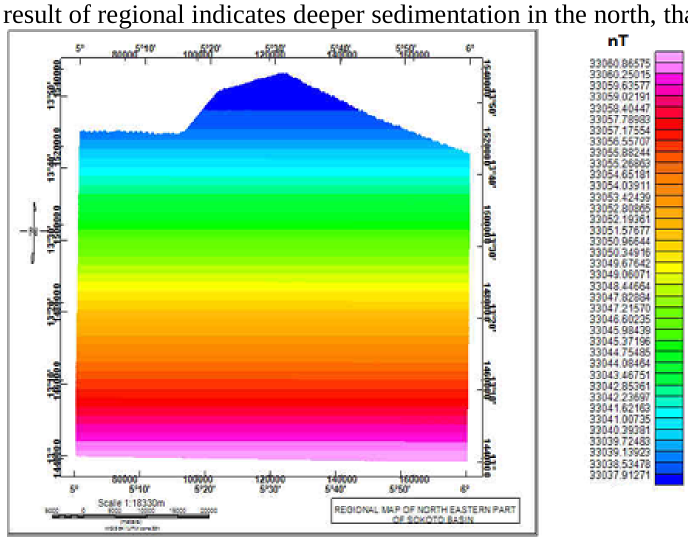

Figure 4: Regional map of north eastern part of Sokoto basin

3.3 Residual Magnetic Intensity Map

The residual magnetic intensity map in Figure 5 was subjected to qualitative interpretations which involve careful looking and illustrations of the maps in order to infer geologic structures without any processing or modeling anomaly pattern [12]. The explanation of the anomalies in terms of their possible causative geological bodies, structures and zoning of a magnetic map is an essential aspect of qualitative interpretation. It involves the delineating of those areas with distinctive or clearly-defined anomaly pattern on a magnetic map that appear to the interpreter as distinct geological rock units. It is a vital tool in geological mapping because it tends to improve the details on the geological map especially in areas that have little or no bedrock exposures [13].

The contoured residual mapof the anomaly in Figure 5 was used in the qualitative interpretation instead of the original (TMI) anomaly map, because it may provide direct evidence of the existence of the reservoir type structures or mineral bodies. The study area can be subdivided into five (5) magnetic zones, each having a unique magnetic anomaly pattern (Figure 5); this magnetic zoning is mainly dependent upon the magnetic properties (e.g. magnetic susceptibilities) of the underlying rock types and the zones may comprise a number of separated domains having similar characteristics.

Zone A, is characterized by short-wavelength (high wavenumber), elongated and near circular magnetic anomalies. The magnetic anomalies, although not related to any features on the geological map, may be expressions of probably an uplifted basement ridge (horst) beneath the sedimentary sequences in the area.

Zone B, shows intermediate (positive), long-wavelength magnetic anomalies. The anomaly, outlines the surface exposures or outcrops of the rivers, and other acidic igneous rock such as (granite, obsidian, pumice) within the study area.

Zone C is also a magnetic zone dominated by yellow-red color, which describes by the Precambrian crystalline basement rocks (migmatites, gneisses and older granites). It exhibits high (positive), relatively complex, high wave number-wavelength.

Zone D is characterized by very low (highly negative), long-wavelength (low wavenumber) magnetic anomalies that are smooth over considerable distances. Anomaly patterns within this magnetic zone shows that it can be categorized into four (4) sub-basins, tentatively referred to as: D1 (SabonGari Dole, Gidan Ruga, Kaura, Damba, Salewa, and Kwakwazo), D2 (Salame, Ruwan Wuri sub-basin), D3 (Dukanmaje, Gadaand Gilbedi sub-basin) and D4 (KyadawaHolai). D1 and D2 are characterized by deeper geologic sources and thick sedimentary cover while D3 and D4 considered as shallow geologic sources and shallow sedimentary cover.

Zone E occupies a large portion at the middle of the residual map. It displays relatively low (negative) to moderate (positive) magnetic anomalies. It is underlain by the Jurassic younger granites (especially biotite granite type), which are sources of cassiterite, columbite and wolfram mite according to [14]. It could thus be inferred that the anomalies within Zone E may be associated with the above-mentioned mineralization or other metal liferous mineral deposits.

Magnetic Zones D, A and E occur within the part of the area underlain by Cretaceous sedimentary rocks. They show large variations in the magnetic intensities which are due to variations in magnetic properties of the constituent sediments and/other geological bodies (e.g. barite ores, lead–zinc sulphide deposits, sills, dykes, volcanic rocks, basaltic lava and coal) emplaced into the sedimentary strata.

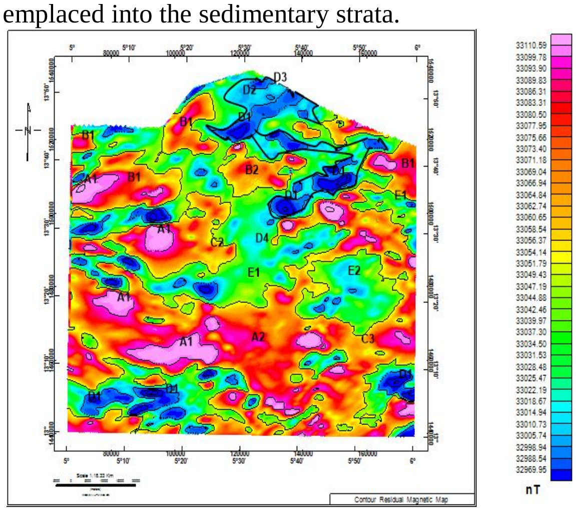

Figure 5: The simplified outlined geology on the residual magnetic map

4. Conclusion and Recommendations

The mode of occurrence and geologic features of coal in north eastern part of Sokoto basin, has been deduced from the analysis and interpretation of aeromagnetic data Sheets (3, 4, 10 and 11), (namely, Kalmalo, Gada, Sokoto, and Rabah) respectively. Result from the interpretation indicate Gada, Dukanmaje, Kwakwazo, Kaddi, and Kyadawa Holai as the potential site for coal prospecting due to their very low (highly negative), long-wavelength (low wave number) magnetic anomalies that are smooth over considerable distances and traces of coal that was found in the near surface of those areas. A complimentary geophysical prospecting preferably seismic method is recommended to be carried out in the study in order to deduce and establish the thickness and actual depth of the anomaly that is required to calculate the possible tonnage of the formation.

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