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STRUCTURAL PATTERN DEDUCED FROM AEROMAGNETIC DATAOVER PARTS OF NASARAWA AND ENVIRONS NORTH-CENTRAL NIGERIA.

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ABSTRACT

Interpretation of high-resolution aeromagnetic data over Nasarawa area was carried out to observe near surface source magnetic features that are associated with geological structures in the study area, Prominent lineaments in this study may be related to fractures that were not revealed by previous studies. Some of these lineaments coincide with concealed faults and fractures at Akiri warm spring and vicinity. Because this area has known warm springs, faults or fault intersections at depth can lead to upward movement of warm water that enhances permeability. Thus, mapping concealed fractures provides a focus for follow-up geothermal studies. Fault interpretation was accomplished by synthesizing interpretative maps derived from first vertical derivative and analytical signal along with preliminary depth estimates. Faults were interpreted along linear aeromagnetic anomalies and breaks in anomaly patterns. Many linear features correspond to topographic features, such as drainages. A few of these are inferred to be fault-related. The interpreted faults show criss-crossing pattern of fault zones, some of which appear to step over where they cross, and show zones of west-northwest, north-, and northwest-striking faults that cross west-northwest around Akiri warm spring. North easterly striking faults extend east from this juncture. The associated aeromagnetic anomalies are likely caused by magnetic contrasts associated with rifting of crust beneath the Benue Trough.

KEY WORDS: Derivative, Structural Pattern, Rift Zones, Akiri.

INTRODUCTION

Geothermally active areas around the world are generally associated with rift zones, where deep, hot water is brought to surface through fractures or faults (Duffield and Sass, 2003). Understanding the nature of basin faults along which the thermal fluids flow is key to successful exploration for new geothermal resources in these environments. However, basin faults are commonly covered by alluvium, making them difficult to locate and map, but recent developments in aeromagnetic data collection and processing have increased the sensitivity of the technique to the point where structures within the sedimentary sequence are detectable, the ability to display both amplitude and gradient information (shaded relief displays) and easily change display scales reduced the level of skill and effort required to extract structural and litho- logical information from the data. The magnetic field of an area is influenced by geological structures, geological composition and magnetic minerals, most often due to changes in the percentage of magnetite in the rock. Complex structures underground due to geological bodies can wrap the pattern of the earth's magnetic field into different shapes (Grant and Martin, 1966). The magnetic anomaly map can reveal the geological structure of the upper crust of the Earth, the presence of faults and folds (Atchuta and Badu, 1981), aeromagnetic maps are important geophysical tools for mapping geological structures in exploration survey (Smith and O'Connell, 2007). A study of these shapes on a magnetic map can reveal much information about the features that are underground. This information can include the location, size and shape, volume or mass, and depth of the features; in some cases, the age of a feature and its material (stone, soil, metal) may be estimated (Telford et al., 1990).

The study area is located between longitudes 8^0 00\`E and $10^0$ 00\`E and latitudes 7^0 30\`N and $9^0$ 30\`N in north central Nigeria (Fig. 1). The area is part of the Middle Benue Trough that is noted for hosting economic minerals, it covers an approximate area of 48,400 km^2, and covers farmlands, villages, towns, game reserves, natural reserves etc. Topographically, the study area is hilly at the northern fringes and drained mainly by river Benue and its tributaries in the southern part, it is characterized by moderate relief with high granitic hills generally extending several kilometers, having the NE – SW direction and forms several peaks of relatively higher elevation than the surrounding rocks. The

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prominent peaks are Pankshin (490.73m), Wase,(450.80m) Kagoro hills(211.53m) Mada hills and Eggon hills (236.22m) (Geological Survey of Nigeria bulletin No.5 and 19). The area is in general undulating. Despite the hilly nature of some part of the study area, there are still good road networks, foot-paths and tracks in the area. Major roads found in this area provide access road to the southeastern part of Nigeria and some other communities in the study area such as Akwanga, Nasarawa-Eggon, Lafia, Keana, Awe, Doma, Shendam, Pankshin to mention few. There are other minor roads that provide access to smaller settlements, farms, rivers and streams. The area is marked by two distinct climatic conditions, temperatures in this area range from 20°C - 27°C, while at night, temperatures could be as low as 10°C, Months of March to June experienced increasing temperatures as the rainy season set in sometimes daily temperature could be above 35°C. The rainy season lasts usually from May/June to September/October depending on the rainfall pattern for the particular year, with mean annual rainfall of 1560mm. The dry season is usually heralded annually by the dry, cold Harmattan winds and occurs between November and March. After the departure of the Harmattan and in the absence of rain, the hot sunny season with temperatures exceeding 27^{o}C sets in (Balogun, 2003). The mean annual temperature of the area is 20^{o}C.

This study is an attempt to interpret in geological terms, the high resolution aeromagnetic data of study area with the objective of defining structures, lithologies and geothermal potentials over Akiri and vicinity. It is believed that this would reveal the structural tectonics of Akiri warm spring

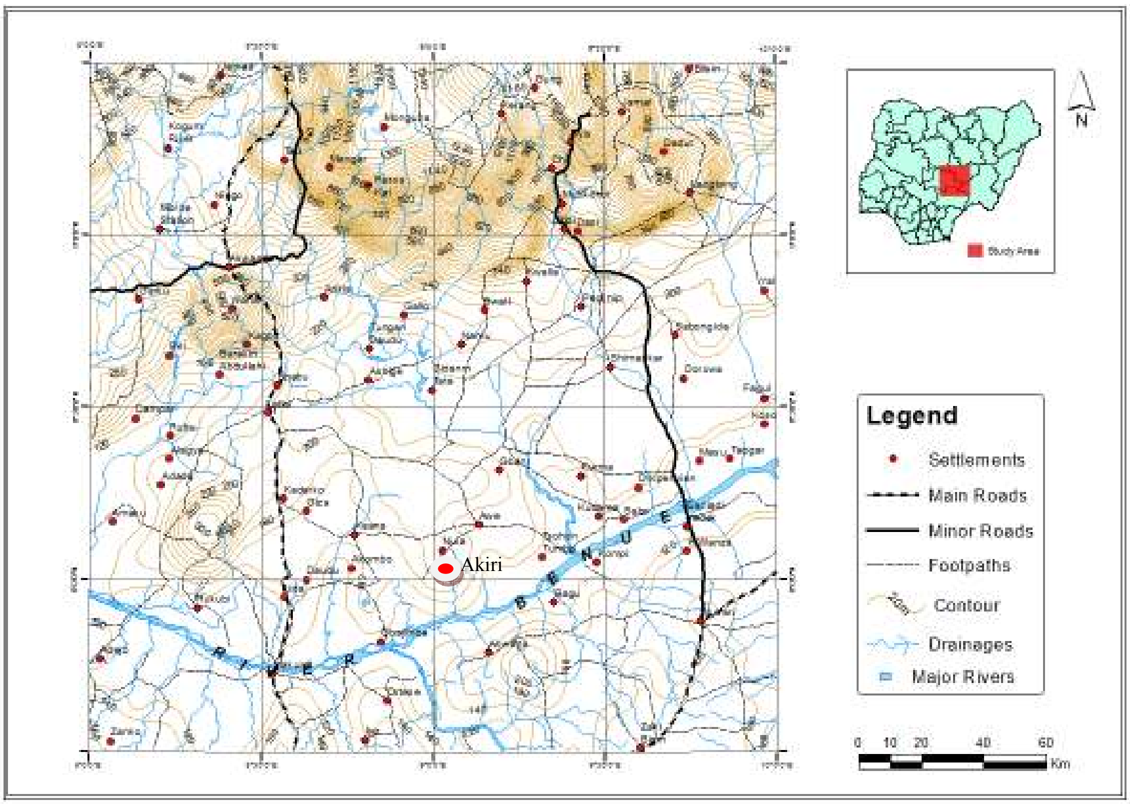

Figure 1.: Topographic Map of the Study Area(After United State Geological Survey.2012)

Geology of the study area

The study area lies within the Basement complex of North-central Nigeria and the Cretaceous sediment of the Middle Benue Trough. It consists of various rock units which have been reported to occur in this area (figure.2). It is underlain by Precambrian basement rocks, remobilised by the Pan African episode (600-500,ma) and uplifted relative to the surrounding areas (Nnange et al 2001).The basement complex rocks are mainly granulitic gneisses, migmatite and older granite. The Jurassic (145-210 Ma) Younger granites in the study area are high level, anorogenic granites; they mainly consist of microgranites and biotite granites, porphyries and rhyolites which outcrop at the northern fringes.

(a) Asu River Group, which consist of mixture of lava-flows, dykes and sills representing the first middle Albian episode into the Benue Trough. This group, which is believed to be about 3000m thick, lies uncomfortably on an older basement complex. Rock units belonging to the Asu River Group outcrop along axis of the Keana (Offodile, 1976).
(b) Awe Formation, which consists of flaggy, whitish, medium to coarse – grained sandstones interbedded with carbonaceous shales or clays from which brine springs issue continuously (Ford, 1981; Offodile, 1980). The Awe Formation marks the beginning of the regressive phase of the Albian Sea.
(c) Keana Formation consists of continential fluviatlile sand and shale.

(d) Ezeaku formation comprises essentially of calcareous shale, micaceous fine to medium – grained friable sandstones, with occasional beds of limestone.
(e) Conician Agwu formation consists mainly of black shale, sandstones and local coal seams.
(f) Lafia Formation is the youngest formation reported in the Middle Benue Trough and consists of coarse-grain ferruginous sandstones, red loose sand, flaggy mudstones and clays (Offodile, 1976).

The Tertiary- Recent volcanic rocks which consist of the Basalts, Trachyte, Rhyolite, and newer basalts of Sura volcanic line also occur in the area.

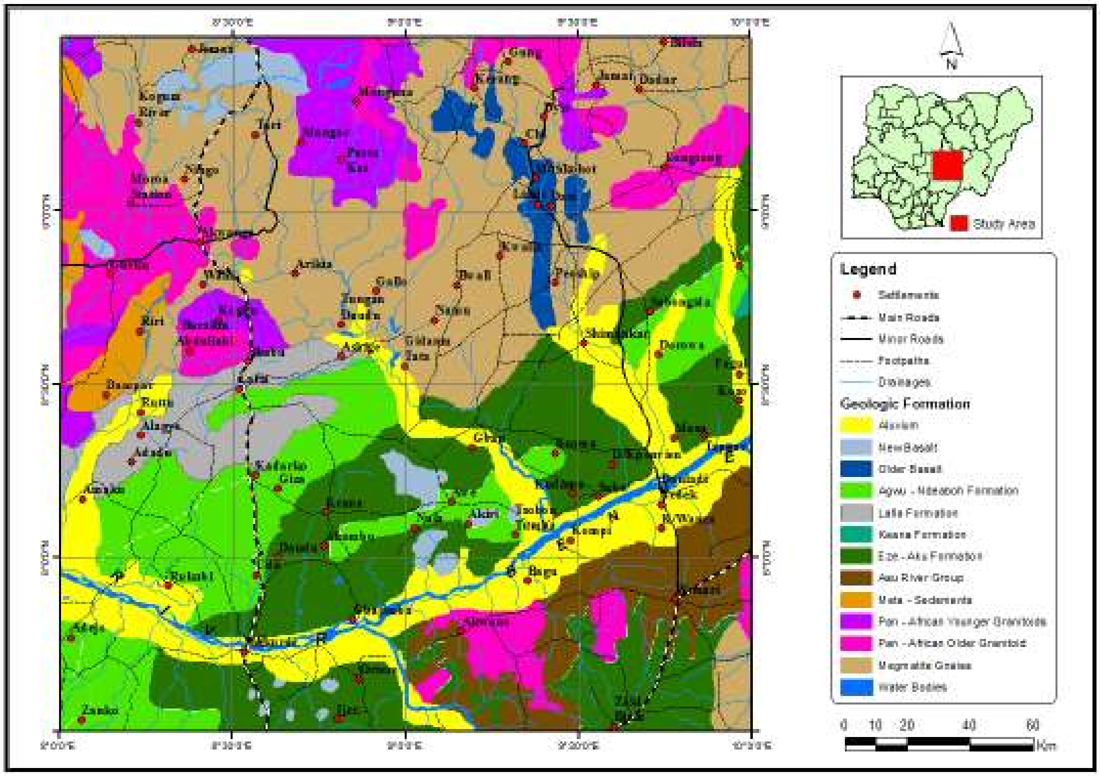

Figure 2.: Geological map of the study area (Adapted from the Geologic Map of? 2006).

Materials and Methods

The high resolution aeromagnetic data (HRAM) used for this work was obtained from the Nigerian Geological Survey Agency (NGSA) Abuja, which had acquire digital data for the entire country between 2005 and 2009, The airborne survey was carried out for the Nigerian Geological Survey Agency by Fugro airways services, the surveys was flown at 500m line spacing and at an average flight elevation of 80 m along NW – SE direction, and published in form of grid (digital form) on 30\` by 30\` sheets. The IGRF of 2005 has been removed from the data and many errors usually associated with the old map are eliminated. Sixteen sheets were assembled for this work with each square block representing a map in the scale of 1:100,000. Each square block is about 55 x 55 km^2 covering an area of $3,025km^2$ hence the total area studied is about $48,400km^2$, the digital data was acquired as merged unified block and processed by means of a computer program Oasis montage version 7.5. This data was used to evaluate the fracture system of study area using the first vertical derivative, analytical signal and Euler deconvolution techniques

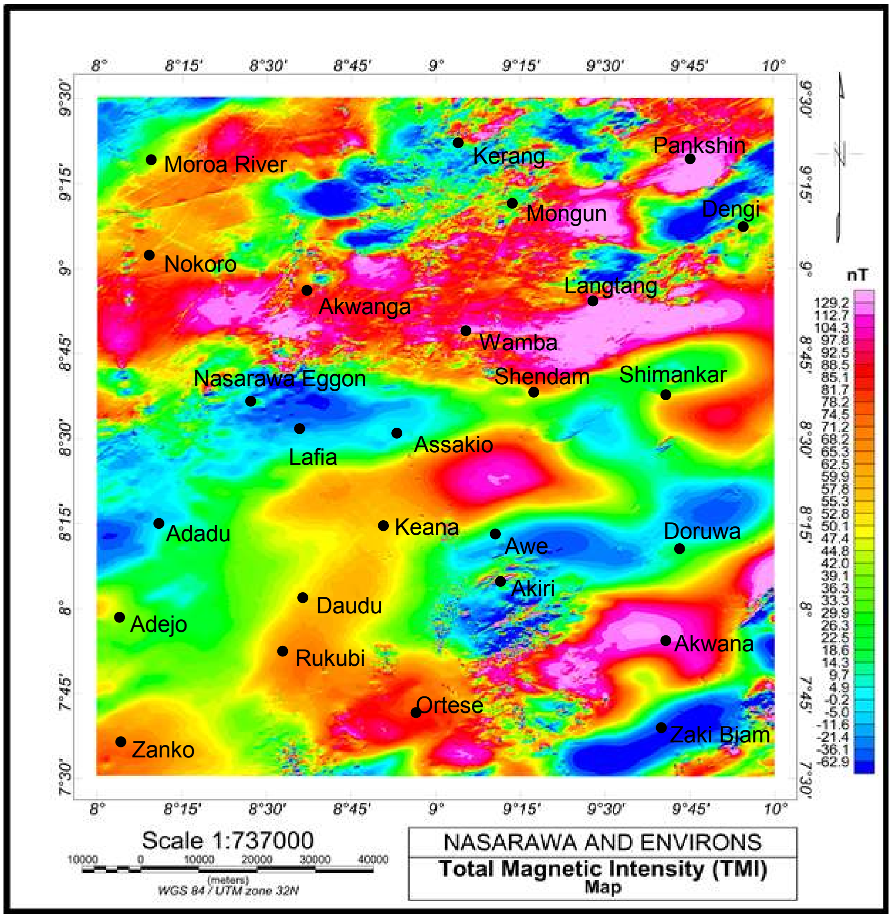

Figure 3.: Total Magnetic Intensity Grid Map of the Study Area. (To obtain the actual total magnetic field value, add 32,500 nT to the values shown in the key).

To remove the regional magnetic field, which is the anomaly associated with low frequency components, a plane surface was fitted to the digital data by polynomial fitting least square analysis. In this method, the matching of regional by a polynomial surface of low order exposed the residual features as a random error, the treatment is based on statistical theory. The observed data are used to compute, usually by least squares, the mathematically describable surface giving the closest fit to the magnetic field that can be obtained within a specified degree of detail (Skeels, 1967; Johnson, 1969 and Dobrin, 1988). This surface is considered to be the regional and the residual is the difference between the magnetic field value as actually mapped and the regional field value, thus determined (Udensi, 2000).

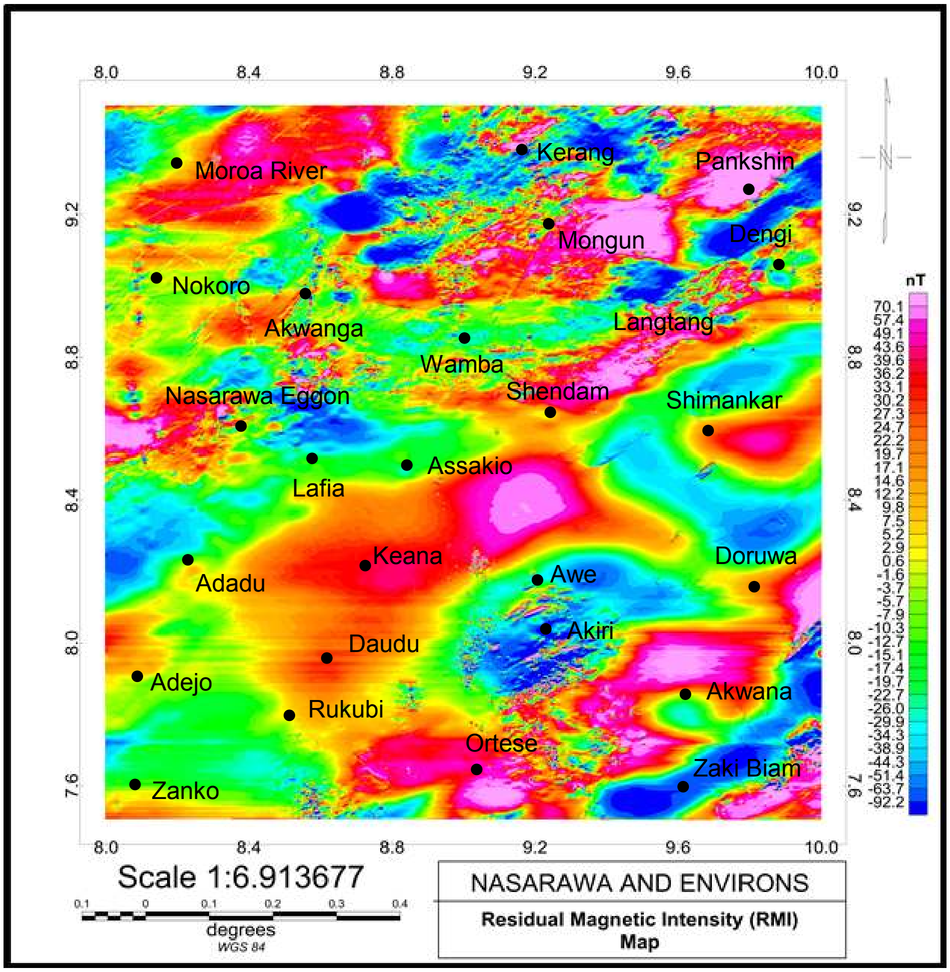

Figure 4. Residual Magnetic Intensity Grid Map of the Study Area

First Vertical Derivative (1VD)

The First vertical derivative has shown to be a useful technique in the processing of magnetic data; it is a filtering technique that is equivalent to enhancing shallow sources and suppressing deeper sources. This technique amplifies short wavelength and it is relatively insensitive to noise. The transform is a useful interpretation tool in the determination of shallow seated fractures and faults by making the edges of shallow seated anomalies become sharper or clearer. The mathematical expression involved is given by:

$$VDR = \partial A / \partial Z$$

The First vertical derivative (1VD) was applied to the residual magnetic intensity (RMI) data using Geosoft Oasis Montaj software and this produced the first vertical derivative grid map. The (1VD) filter enhance the high frequency and short wavelength part of the data, which allows small and large amplitude responses to be more equally represented to observe near surface source magnetic features that are associated with geological structures in the study area. The colour and grey images of the first vertical derivative (Fig.5a & 5b) enhanced the image by showing major structural and lithological detail which were not obvious in magnetic residual map (Fig. 4), thus the colour and grey-scale images complement each other.

Inspection of the map revealed a strong NE-SW linearity of the anomalies suggesting that the NE-SW is the dorminant trend in the area, other trends revealed include the NW-SE, NNE-SSW, E-W and N-S, at the northern fringes of the study area where rock outcrop on the surface, faults (or linear contacts) were interpreted both in colour and grey images as abrupt differences in patterns while at the southern part and the low-lying areas, many linear features are apparent and accentuated in the grey map (fig. 5b), most of these appear to arise from contrasts within the basement.

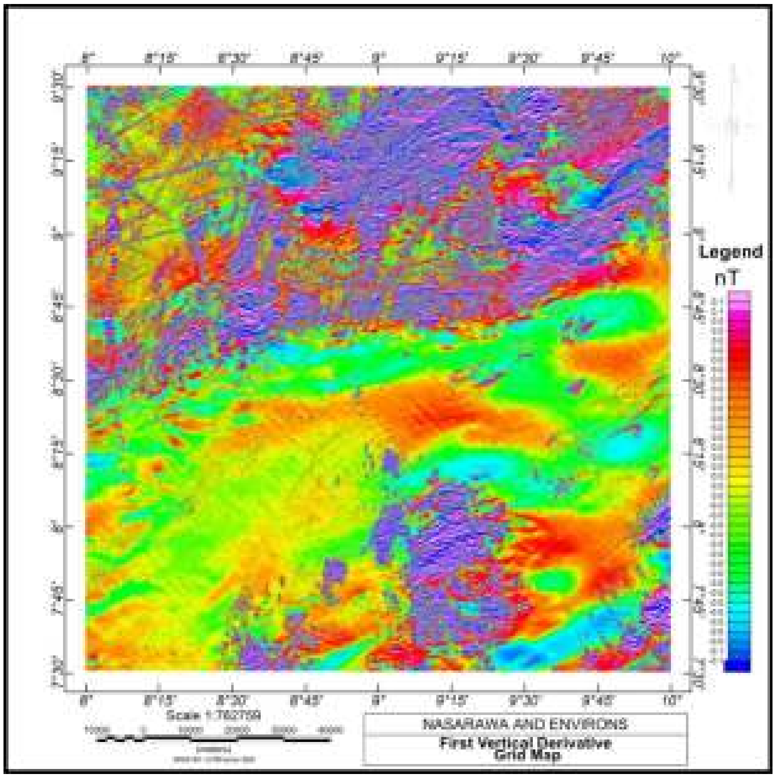

Figure 5a First Vertical Derivative Map of the Study Area.

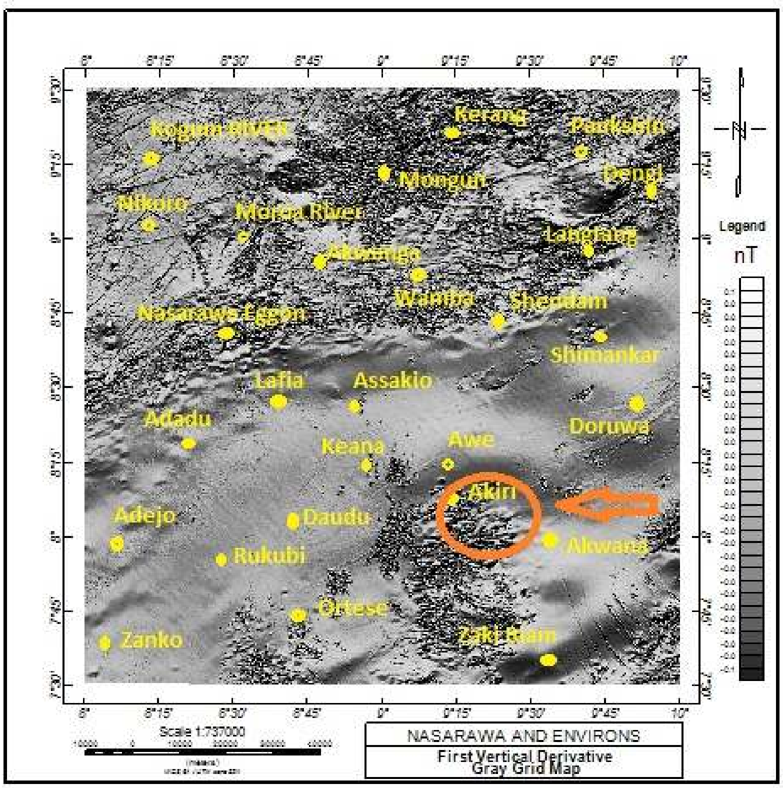

Figure 5b.First vertical derivative map. (grey scale map)

Analytical signal

The Analytical signal is also an excellent tool for the interpretation of magnetic data, though the transform is complex from the differentiation of a potential field data that is also complex (Nabighian, 1972). In this technique, the magnetic derivatives are calculated in the x, y, z direction, and the square root of the sum of the square of the derivatives gives the analytical signal (Roest et al., 1992). It is also called the total gradient method because it involves the derivatives in all directions. Analytical signal has been found to be very useful in the transformation of magnetic anomalies because it can performs well at all magnetic latitudes it is good in locating contacts and sheet like structures by forming maxima around the edges of magnetic sources. The mathematical expression involved is given by:

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

The Analytical Signal was carried out in this study to confirm structures and lineament pattern in the study area. The analytical signal technique was applied to the residual magnetic data using Geosoft Oasis Montaj software and this produced the analytical signal map (fig. 6). The result revealed colour ranges like the total magnetic intensity map, with red as high and blue as low. It is characterized by very low amplitude magnetic anomalies, the general trending fabric of the analytical signal map is also in the NE-SW direction, a low magnetic anomaly of 0.01nT was observed at the south-eastern part of the study area correspond with thick sedimentary sequence, while magnetic anomalies of 0.2047nT correspond with the volcanic intrusions at the extreme north and southern-eastern part of the study area.

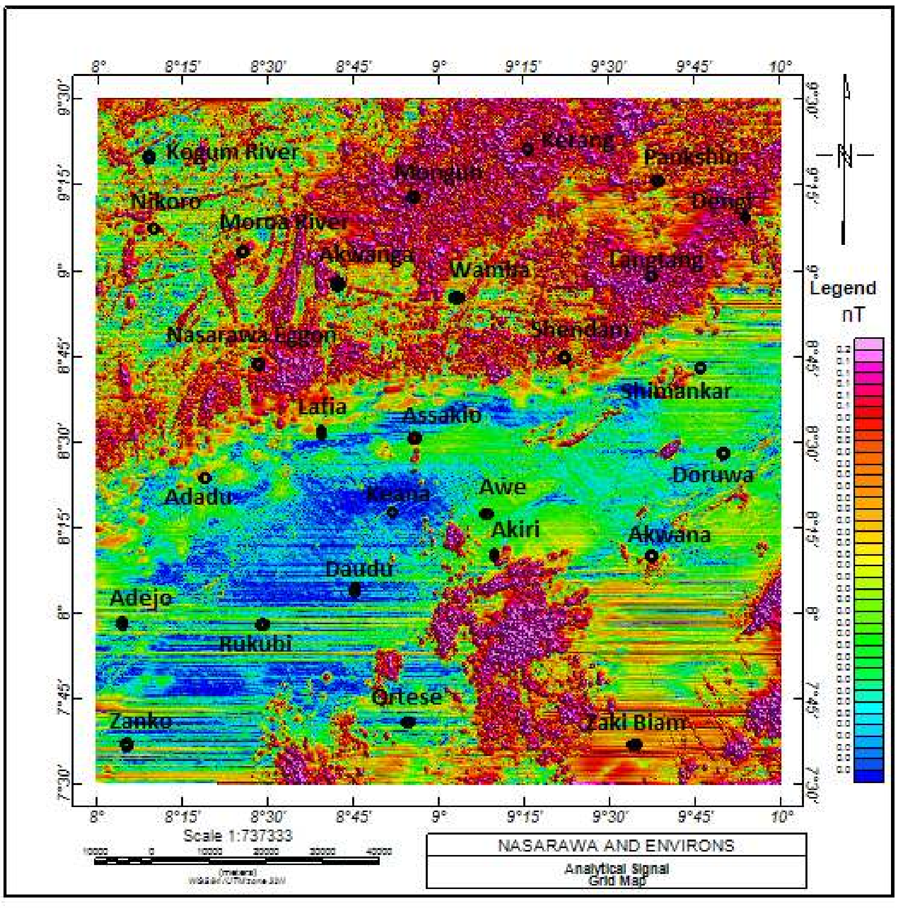

Figure 6. Analytical Map of the Study Area.

Further inspection of this map revealed contacts of faults, fractures and joints that are probable site for transmitting geothermal fluids and hosting mineralization. The analytical signal shows several bell shaped closures represented by pinkish closures, the alignment of these closures tend to mark out likely trends of magnetic lineaments.

Like the First vertical derivative processing techniques in the study, magnetic anomalies (fracture zones) trending in the NE-SW, NW-SE, NNE—SSW, NNW-NNE, E-W and N-S directions were observed. These identified fault/fracture trends could be attributed to extensional basin tectonics that created the Benue trough. Evident also around Monguna, Mangar, Kerang, is a magnetic anomaly that appear elongate at the extreme northern part, aligned along the NNE fracture directions which correspond to the volcanic rocks in the geologic map, several other magnetic anomalies that depict structural disturbances are also present and correspond with other derivative in the study. The analytical signal also revealed bell shaped pinkish closures around Akiri warm spring signifying structural disturbance in the vicinity. The south-western part of the study area reveals blue coloration (magnetic low) this could be due to sediment thickness. The difference in magnetic relief like other transform between each two adjacent magnetic highs and lows suggest a comparable variation in lithology. This map also gives a well-defined basement-sedimentary boundary which implies that the analytic signal map can be an effective tool as an indicator of abrupt changes in magnetic continuities over the study area. This output clearly show that this method is a good at confirmatory technique.

Euler Deconvolution

The application of Euler deconvolution has emerged as a powerful tool for direct determination of depth and probable source geometry in magnetic data interpretation (Roy et al. 2000; Barbosa et al, 1999; Muszala et al.1999. Euler derived interpretation is not constrained by any preconceived geological ideas and thus can be used critically to appraise geological and structural interpretations (Reynolds, 1997).The method is based on the concept that anomalous magnetic fields of localized structures are homogeneous function of the source coordinate and, therefore, satisfies Euler's homogeneity equation. The method operates on the data directly and provides a mathematical solution without recourse to any geological constraints. The mathematical expression involved is given by:

$$(x - x_0)\frac{\partial T}{\partial x} + (y - y_0)\frac{\partial T}{\partial y} + (z - z_0)\frac{\partial T}{\partial z} = N(B - T)$$

where:

(x_0, y_0, z_0) is the position of the magnetic body

T-Total field measured at (x,y,z)

N- the degree of homogeneity which can also be interpreted as the structural index (SI) is the variation of the field with distance.

B- Background value of the TMI or the regional field

This method depends on the structural index, level of the magnetic data and the sampling rate, it uses both the horizontal and vertical gradients, to calculate the location and the depth of the anomaly sources. For the magnetic data structural indices SI = 1.0 (for magnetic dykes) and SI = 0.5 (for magnetic fault) (Reid et al., 1997) are used. However, Reid et al. (1990) showed that the structural index of0.5 leads to underestimates of depths and the value of a sloping contact is in fact zero as long as an offset A is introduced and hence Euler's equation can be written as

$$(x - x_0)\frac{\partial T}{\partial x} + (y - y_0)\frac{\partial T}{\partial y} + (z - z_0)\frac{\partial T}{\partial z} = A$$

The Euler deconvolution technique was carried out on the magnetic data of the study area to determine contacts, faults and depth to the causative source type. Therefore to derive the depths to the basement within the study area, the Total Magnetic Intensity (TMI) data was used as input into the Euler deconvolution window of a computer software Oasis Montaj version 7.5. The data is divided into square windows within the grid and Euler assumes a structural index and a regional value B to derive least-squares estimates for optimum source geometry within a data window. Care was taken in choosing a structural index because values that are too low will give estimates that are too shallow and high values can give abnormally deep estimates. The Euler deconvolution requires derivatives in the x,y,z directions so these were derived in Geosoft. A folder was created for the solutions that are stored as a.gdb file. Most of the anomalies in the grid are between 1 km and 3 km in width and as the grid cell size of the data is 200 m, a window size of 20 was selected which corresponds to a search window size of 4 km. The maximum distance from the centre of the window to accept was set as 0 which stands for infinity.

The depth to the subsurface structures ranges between 400 and 900 m. The Euler solution at different depths is shown in (Fig. 7). The depths to the detected faulting pictures of the subsurface structures range between 1.00 to 2.00 km with mean depth of 1.5 km.

The solutions generated were analyzed and values greater than 7km were discarded since the thickest sediments in the Benue Trough have been found to be about 7 km (Carter et al., 1963) and the middle Benue has been observed to be the shallow part of the Trough. The data was exported as a shape file and gridded in Arc Map. The depth to the magnetic basement in the area ranges from about 1 km to about 3 km in most of the southern part of the area

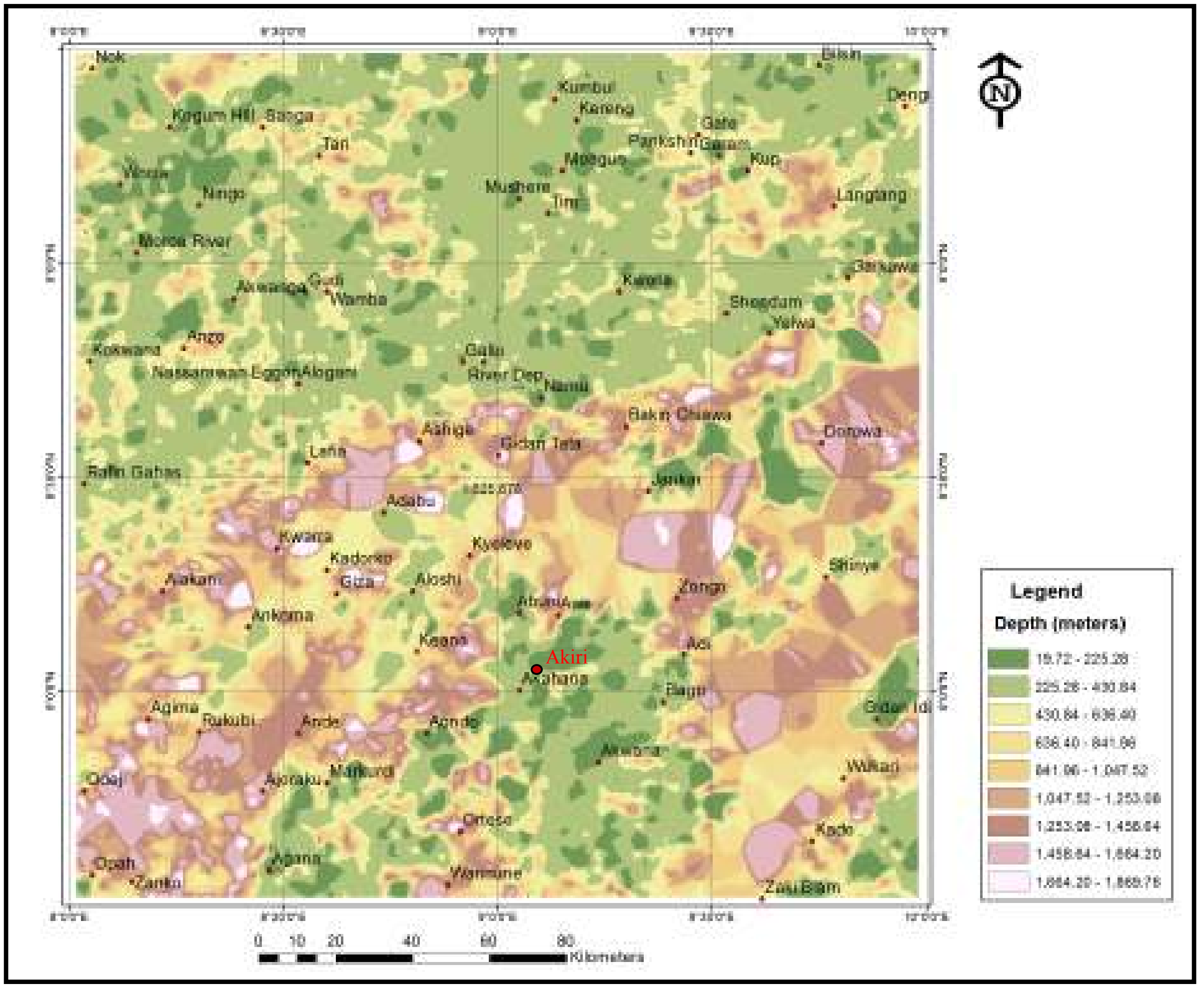

Figure 7. Euler Deconvolution Map of the Study Area

Discussion of Results

The magnetic intensity over Nasarawa and Environs showed magnetic signature in the form of colour ranges with red as high and blue as low and clear disposition of different zones with distinct anomaly ranges. The difference in magnetic relief between two adjacent magnetic highs and lows suggest a comparable variation in Lithology. Bearing this in mind, prominent magnetic relief between two adjacent magnetic highs and lows, elliptical closures and nosing were identified on the magnetic map, these features represent geologic anomalies/lineaments. Aeromagnetic anomalies over the area consist of slow to fast varying types, the former occupy a broader part of the area and is coincident with the sedimentary cover, while the latter is a concentrated sequence almost restricted to the northern zone of the area and coincident with the suit of Mesozoic alkaline and pre-alkaline granites and volcanic which include rocks such as rhyolites, granites, subordinate syenites, gabbro, dolerites and basalt that have been emplaced along pre-existing basement lineaments, including ring fractures.

The airborne magnetic data generated high resolution images that show major lithologies and structural features that may be present in the study area. Interpretation of these images was carried out visually to delineate geological structures. Rocks of the study area showed different magnetic responses that can be related to their lithology and tectonic activities which have resulted in the geological structures in the area. Linear features associated with the volcanic rocks; sandstones and shale are observed as moderately low and low magnetic signature.

The results of the first vertical derivative emphasized the effect of near surface anomaly sources and made the edges of shallow seated anomalies become sharper or clearer, this enhancement revealed fault pattern as illustrated in (fig 5b). These high density faults with crisscrossing pattern shows evidence of faults, fractures, joints folds, thrusting and other structures related to the Pan-African orogeny, which may reflect structural transition between rift basins; these identified trends are attributed to tectonics activities in the area. Also, inspection of the grey image map reveals numerous north-south-striking faults in the mountainous terrain that appear to control rivers and stream channels in the area, some of these trends could be pegmatite that could host mineralization, evident also are two major trends at the extreme north-central part of the study area that cross each other around Mongun, which could be the major tectonic event that led to the formation of the volcanic rocks in the area and by extension the crater lake at Kerang. Conversely, faults mapped at the southeastern part of the study area may have magnetic expression evidence of thrusting, in another comparison, the geothermal reservoir at Akiriwarm Springis generally located where multiple east-west striking faults paralleling the range front merge with northeast striking intrabasin faults. The numerous fault intersections and complex fault patterns suggest a high density of faulting in the vicinity of Akiri Springs, where basement rocks are involved in the faulting, the fracturing could enhance permeability that allows geothermal fluids to migrate or collect (Smith et al, 2002). The location of the warm springs at the intersection of northeast- striking interpreted fractures and an east-striking mapped faults suggests that the Akiri warm spring occur as a result of tectonic activities in the area.By analogy, the high fault density indicated for the Akiri Springs area provides many opportunities for follow-up geothermal investigations.Similar faults were interpreted using High Resolution Aeromagnetic Survey Data at Poncha springs and vicinity, Chaffee County Colorado, USA (Grauch, 2002).

A depth analysis of the aeromagnetic data is beyond the scope of this study. However, to aid interpretation of causative features, preliminary depth estimation was performed using euler deconvolution method, the method relates spatial gradients of the measured magnetic field to the depths of sources, based on the general principle that shallow sources produce anomalies with steep gradients, whereas deep sources produce anomalies with broad gradients. Depths that correspond to interpreted faults are estimated to be between 225 m to 430 m. The distributions of depths are shown in Fig. 7. The majority of them are in the range of 30-100 m. These estimates are reflective of the depths to the magnetic contrasts that cause the aeromagnetic anomalies and therefore not necessarily the depths to the tops of faults.

CONCLUSIONS

High-resolution aeromagnetic data over Nasarawa and environs was interpreted to observe near surface source magnetic features that are associated with geological structures in the study area, interpretation of fractures was derived from first vertical derivative and analytical signal along with preliminary depth estimates. The result revealed numerous fault intersections and complex fault patterns in the vicinity of Akiri Springs. The location of the warm springs at the intersection of northeast-striking interpreted fault and an east-striking mapped fault suggests that the Akiri warm spring occurred as a result of tectonic activities in the area. The grid of the solutions derived from the Euler method showsth at the depth to the magnetic source in the area ranges from 225 mto 430 m.

RECOMMENDATIONS

- Area around Akiri be investigated further for geothermal energy resources as an alternative source of energy because the high fault density indicated for the Akiri warm Springs area provides many opportunities for follow-up geothermal investigations.
- Groundtooting is highly recommended to confirm the delineated structure and lithology around Akiri and Awe areas.

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