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Research Article

Delineation of Gold Mineral Potential Zone Using High Resolution Aeromagnetic Data Over Part of Kano State, Nigeria

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ABSTRACT

The study of the geometry and kinematics of deep geological structures, bearing mineralization has advanced greatly by the aggressive progress of geophysical techniques over the last decades. The mineralization zones located in the Shanono local government area of Kano state Nigeria has its genesis controlled by shear zones. This research was aimed at delineating and characterizing subsurface geologic structures around the study area. Both qualitative and quantitative analysis of aeromagnetic data has provided defined distinct pattern of the magnetic signatures. Euler solution of the aeromagnetic data with structural index one, revealed the presence of the major tectonic trends of anomalies in the NE-SW and NW-SE directions. The trends of few of these structures are observed to be similar to fracture orientations in the Nigerian basement complex. These structures control the emplacement of the gold mineralization as these provides the pathways to flow of mineral rich fluid within the host rocks of the study area.

Keywords: Gold; Fractures; Lineaments

INTRODUCTION

Nigeria has been known to have a long history of mining and the country was a prominent exporter of minerals such as tin, coal, and kaolin. Gold is generally found in Nigeria as alluvial and eluvial placers and primary veins from several parts of supracrustal (schist) belts, in the northwest and southwest of the country [1]. Several authors have studied the gold mineralization in Nigeria and the host rocks [2,3]. The most occurrences of such gold minerilization are found in the Maru, Anka, Malele, Tsohon Birnin Gwari-Kwaga, Gurmana, Bin Yauri, Okolom-Dogondaji and Iperindo areas, all associated with the schist belts of northwest and southwest Nigeria [1]. All these areas are spatially related to the two fault systems in the region [4] the gold-bearing veins, reefs and stringers are often localized by brittle and ductile fault structures or planes of schistosity that traverse phyllites, schists, quartzites, gneisses and contact aureoles of granitoid masses.

Artisanal mining in Nigeria, has being a means of livelihood adopted primarily in rural areas [5]. This is sometimes called the informal sector, which is outside the legal and regulatory framework [6]. When not properly done, artisanal mining can be viewed negatively by governments and environmentalists, because of its potential for environmental damage, social disruption, and conflicts [7]. Most of these miner's work in very difficult and often dangerous conditions in the absence of the required safe mining regulations to safeguard the operations [5]. The environmental and health implication of mining have long been studied and scientific literature is full of documented cases of damage to the environment and human health directly linked to the mining-related pollution [8-12]. Despite the dangers that this mining activities causes, artisanal gold mining operation continue to spread due to the unattractive nature of other means of livelihoods such as farming and fishing in the rural areas where such mineral exists [13]. These dangers have led to the advanced use of geophysical methods to delineate fault lines associated with minerals, so as reduce the environmental damages caused by artisanal miners.

Geophysical techniques (gravity, magnetics and electromagnetics etc.) have been widely used to get subsurface information of the Earth, without engaging in invasive digging. It has been utilized to solve many problems such as geotechnical, and exploration etc. The basic step is first to identify the physical property, that is, diagnostic of the sought geologic structure in the area of study. The appropriate geophysical survey is then employed, then field data are acquired and plotted. In some cases, the information needed to solve the problem may be obtained directly from these plots, but in most cases, more information about the subsurface is required.

Geophysics has been evolving, and new methods of automating

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geophysics, such as resistivity, magnetometry, very low frequency, gravity and seismology, are being developed. The study of the earth's magnetic field, is one of the oldest branches of geophysics. It has been known for more than three centuries that the earth behaves as a large and somewhat irregular magnet [14]. However, the ground magnetic is always being studied for precise mapping so as to understand the subsurface geology of an area. This technique basically requires measurements of the amplitude of magnetic components at discrete points along traverses distributed regularly throughout the survey area of interest.

Aeromagnetic survey is carried out using a magnetometer on board or towed behind an aircraft, a ship or Boat. The principle is different as compared to a ground magnetic survey carried out with a hand-held magnetometer in the sense that it covers much larger areas of the earth's for regional reconnaissance. The airborne magnetic survey has been used so well in the mineral exploration industry, basically for the characterization of mineralization zones in most parts of the world and as the secondary tool in gold exploration in Nigeria [15,16]. The success of this method is derived from the unique signatures that are produced by the mineralization zones making it possible to distinguish them from the host rock.

The role of aeromagnetic method in mineral exploration varies from delineation structures like faults, folds, contacts, shear zones and intrusions to automated detection of porphyry and favorable areas of ore deposits. There are various enhancement techniques that can help achieve objectives.

Location, climate and vegetation of the study area

The Shanono local government area lies on latitudes 11.962 N to 12.264 N and longitudes 7.979 E to 7.980 E (Figure 1) which is north-east of Kano state, Nigeria. The inhabitants are agrarian, however, with the discovery of traces of minerals at Shanono, they embrace artisanal mining for gold in the dry season to complement farming. According to Olofin [17], the climate of Kano state is the tropical wet and dry type, although some climate changes are believed to have occurred. The natural vegetation of Shanono local government area is the Sudan Savannah type.

Geology of the study area

Shanono local government area of Kano state lies on the Basement Complex rocks of northern Nigeria (Figure 2). The Nigerian basement complex is made up of gneisses, migmatites, and metasediments of Proterozoic age which have been intruded by a series of granitic rocks of Late Precambrian to Lower Palaeozoic age. These rocks have been variably metamorphosed and granitized through at least two tectonic-metamorphic cycles converted to migmatites and granite-gneiss [18,19]. Falconer et al. have reported the occurrence of rocks of the Younger Granites series [20], which are Jurassic in age, as well as volcanic, and occasional younger dikes.

Nigerian schist belts are complexly deformed with earlier folds being refolded by later once and there are some similarities of the dominant deformations in all the belts [21]. The Kazaure schist belt is characterized by upright isoclinal folds with NNE-SSW axial planes and well-developed cleavage formed during the Pan-African orogeny, and relict recumbent isoclinal folds with N-S trending axial plane mostly obliterated [21]. The Malumfashi schist belt is characterized by an early ENE-WSW foliation largely obliterated, and Pan-African orogenic imprints of light to isoclinal ENE-WSW folds with N-S axial plane [22].

Gold mineralization in the study area occurs in a variety of host rocks, but is generally related to the supracrustal schist belts.

MATERIALS AND METHODS

Data source

Four high-resolution aeromagnetic maps (HRAM) were acquired from the Nigerian Geological Survey Agency (NGSA). These sheets include; sheets 56 (Yashi), 57 (Shanono and Bichi), 79 (Malumfashi) and 80 (Karaye). The aeromagnetic data collected by the NGSA between 2005 and 2009 at a flight altitude of 80 m along a series of NE–SW flight lines with a spacing of 500 m. The data were made available in the form of a contoured map on a scale of 1:100,000 grid file. The grid after been superimposed together, extend from 11^0 30' N-12^0 30' N and from 7^0 30' E-8^0 30' E, covering

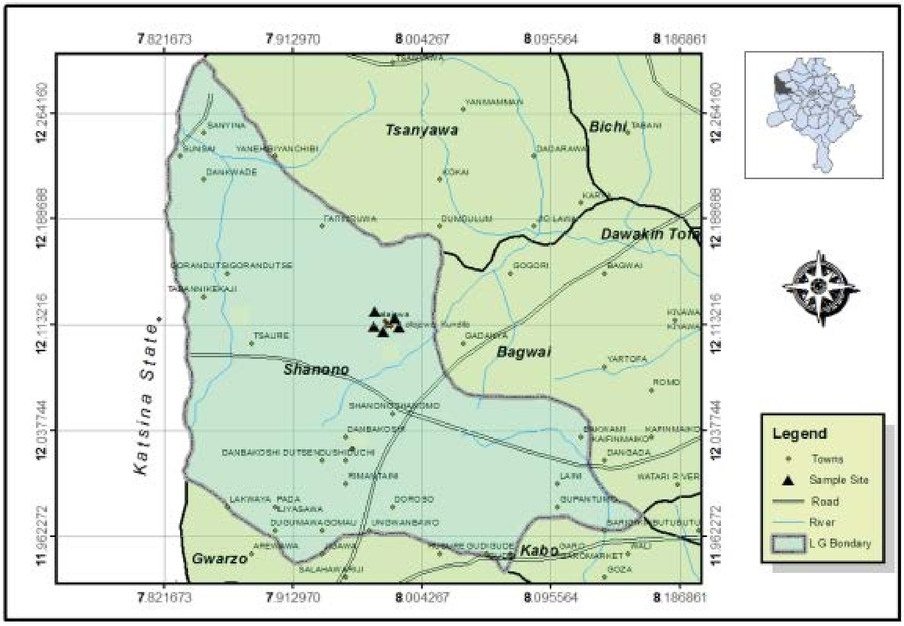

Figure 1: Map showing the location of the study area and environment (Adamu, 2018).

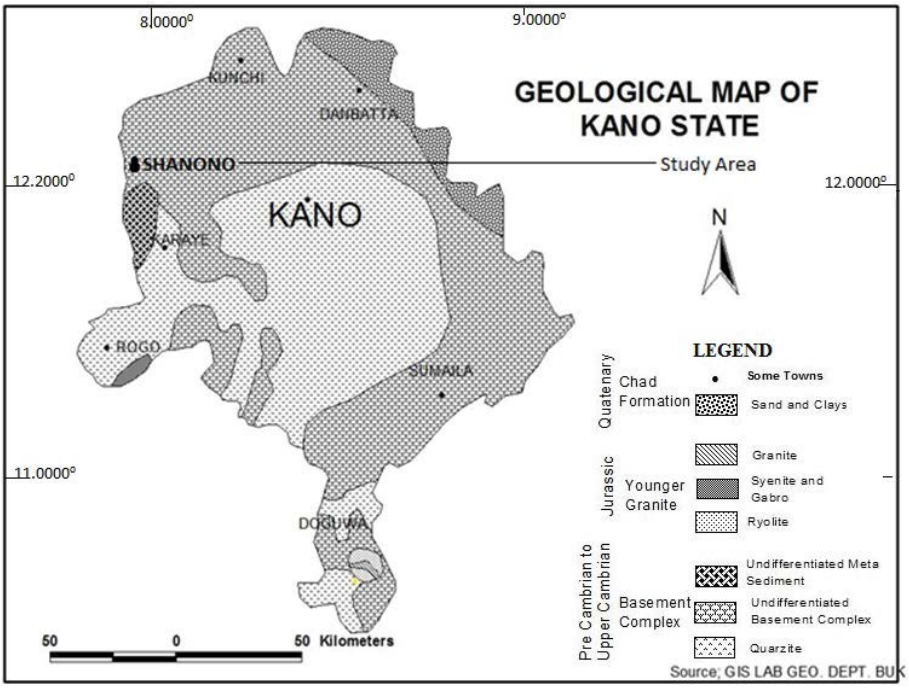

Figure 2: Geologic map of Kano State.

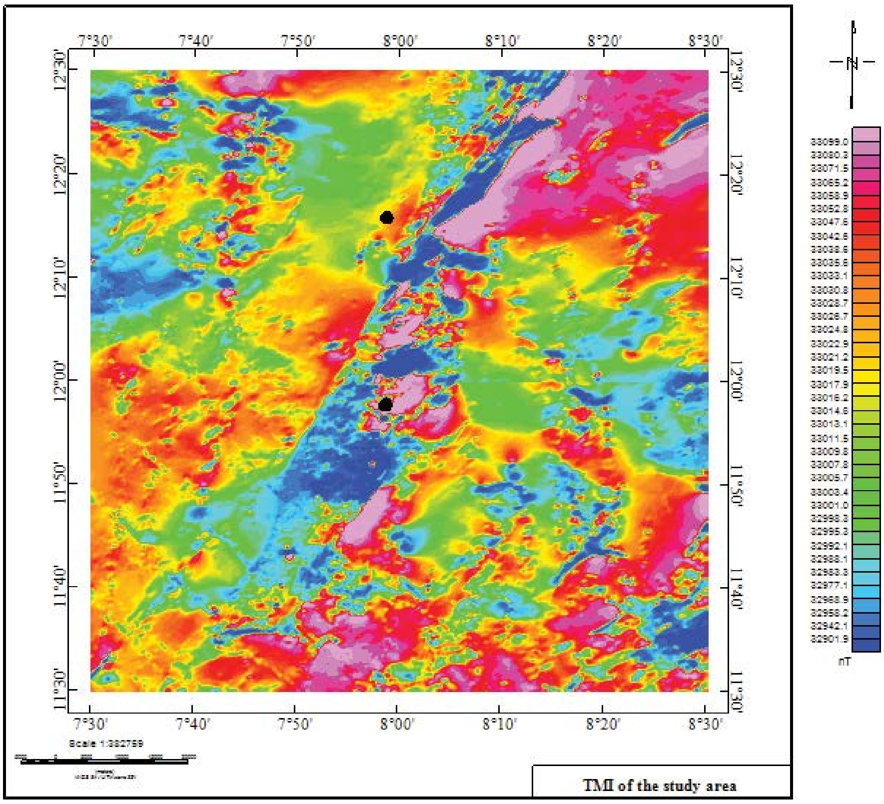

Figure 3: Total magnetic intensity (TMI) of the study area gridded on the oasis montaj software using a grid cell size of 0.00225 degrees (250 m) with the two black points indicating the study area.

the study area. The magnetic field intensity ranges from 33901 to 33099 nT (Figure 3). Oasis Montaj. Ver 8.1 was the software used for the processing.

Analytical signal

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 geologic boundaries such as contacts and faults. The forward and inverse 2-D Fourier transform g and *f* respectively of the magnetic field anomaly, **T** is given by:

$$g(k_x k_y) = F\left[f(x,y)\right]$$

$$= \int f(x,y) e^{-i(k_x x + k_y y)}\, dxdy \quad 1$$

$$f(x,y) = F^{-1}\left[g(k_x,k_y)\right]$$

$$= \frac{1}{4\pi^2} \int f(x,y) e^{i(k_x x + k_y y)}\, dk_x dk_y$$

Nabighian [23] developed the concept of 2D analytic signal, or energy envelope, of magnetic anomalies. The amplitude of the 3D analytic magnetic field signal at location (x,y) can be expressed as:

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

Where, 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 that would result, had an area been surveyed at the magnetic pole.

Euler deconvolution

The objective of the 3D Euler deconvolution process depth estimations of geologic sources of magnetic or gravimetric anomalies in a two-dimensional grid [24]. The method makes use of a structural index in addition to producing depth estimates. In combination, the structural index (SI) and the depth estimates have the potential to identify and calculate depth estimates for a variety of geologic structures such as faults, magnetic contacts, dikes, sills, etc. Usually, Euler deconvolution assumes a tentative SI and estimates four parameters, such as base level, horizontal and vertical positions of an isolated and single-point geologic source. The algorithm uses a least squares method to solve Euler's equation simultaneously for each grid position within a sub-grid (window). A square window of predefined dimensions (number of grid cells) is moved over the grid along each row.

The Euler's homogeneity relation could be written in the form

$$\left(X-X_0\right)\frac{\partial T}{\partial x}+\left(Y-Y_0\right)\frac{\partial T}{\partial y}+\left(Z-Z_0\right)\frac{\partial T}{\partial z}=N\left(B-T\right) \quad 3$$

Where (X_0, Y_0, Z_0) 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* [25].

RESULT AND INTERPRETATION

The contoured digitized data which is referred to as the total magnetic field intensity (TMI) was further processed in order to understand the subsurface geological information. It contains both the regional (deeper subsurface) and residual component (shallow subsurface). The regional-residual separation filtering technique was used to separate regional, which originates due to deep seated sources from the residual anomaly, which in turn is associated with the shallow subsurface geological sources (Figure 4).

The residual magnetic intensity (RMI) grid was continued to 250 m to see deeper signature coming from deeper structures (Figure 5). This process has smoothened the high frequency shallow subsurface features.

First and second vertical derivatives (1VD and 2VD) maps were derived from residual magnetic anomaly (derived from upward continuation). This procedure enhances the enhance shallow structures. Figure 6 shows the first vertical derivative, indicating an anomalous fault line trending towards the study area.

The second vertical derivative image usually tends to reveal more deep-seated features (Figure 7). The 2VD image, shows the basement complex rocks as pockets of intrusive structures displayed in blue pattern. The magmatic induced patterns in the study area are observed and are accompanied by numerous linear features. Within the study areas, it can be seen that high density of these linear structures indicating intense structural perturbation during emplacement.

The Analytic Signal is carried out so as to understand the variation of magnetic sources in the study area. Analytic signal maps serve as a major type of reduction to the pole, because they are not subject to the instability that occurs in transformations of magnetic fields

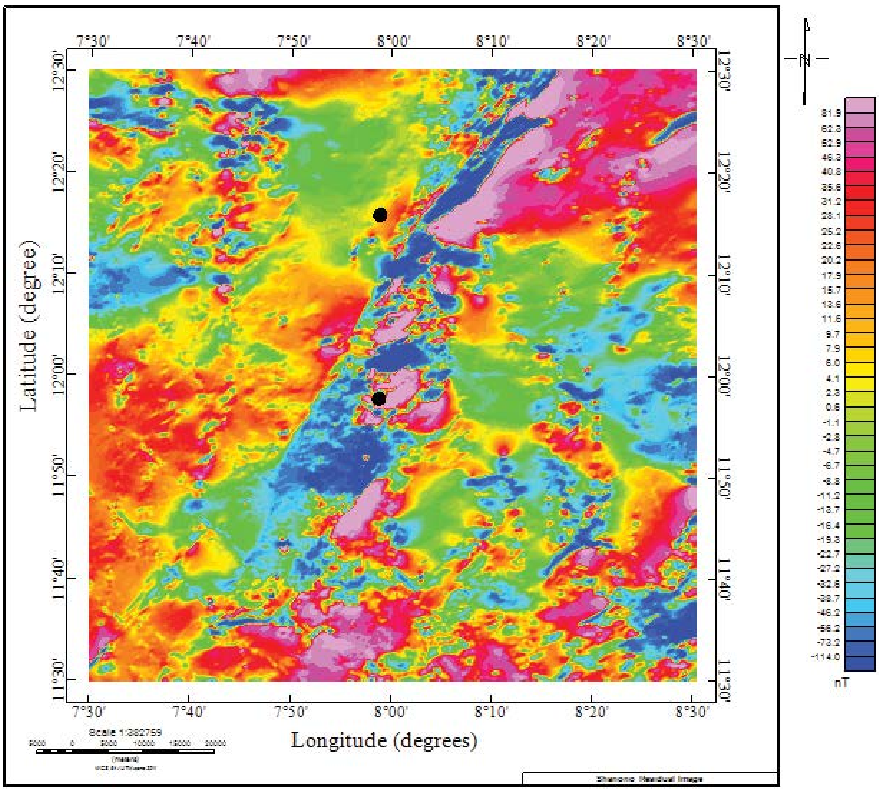

Figure 4: Residual magnetic intensity grid map of the study area gridded on oasis montaj using the minimum curvature method on cell size of 0.00225 degrees (250 m) with the two black points indicating the study area.

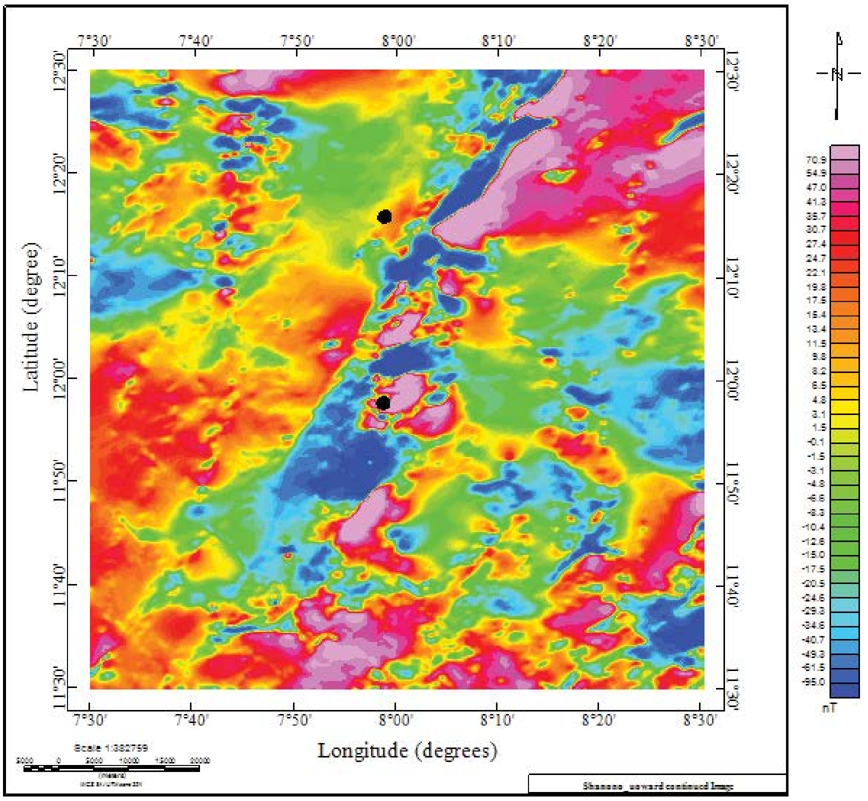

Figure 5: RMI grid continued upward to 250 m above the observation point with the Black points indicating the study area.

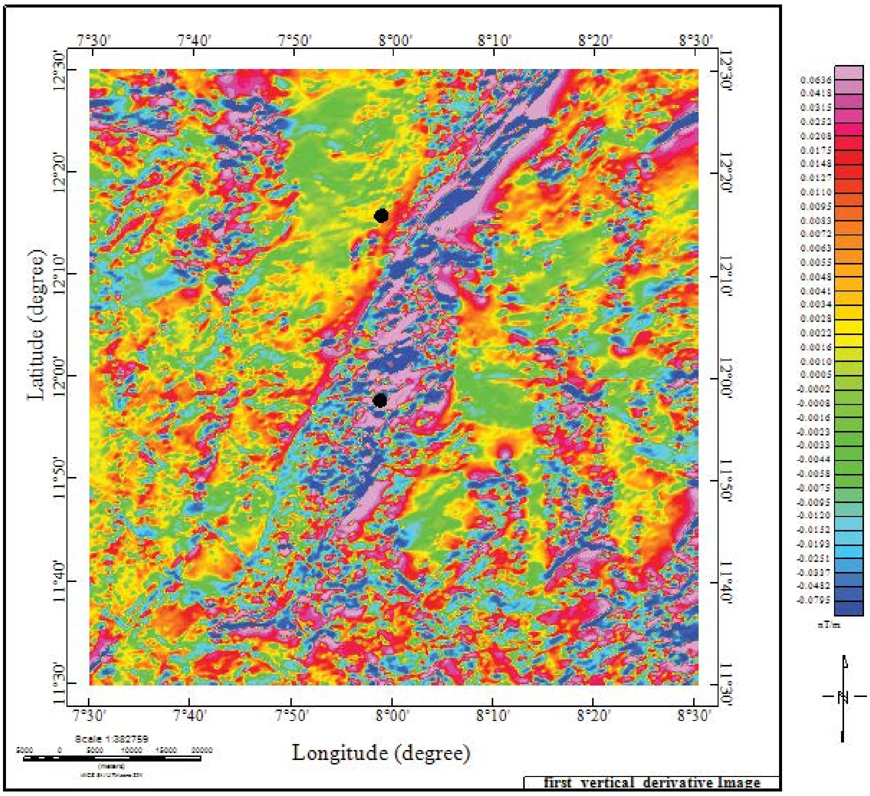

Figure 6: Map showing the First vertical derivative, with the black points indicating the study area.

from low magnetic latitudes. They basically also define source positions regardless of any remnant magnetization in the sources. Figure 8 shows the analytic signal map of the study area, in the space domain. The maxima of the magnitude of analytic signal describes the magnetic contacts between igneous intrusions and the surrounding basement rocks within the study area. It also depends on the magnetic susceptibility contrast between Younger Granite intrusions and the Older Basement rocks. Basic igneous rocks have a higher magnetic susceptibility than acidic igneous rocks.

Three-dimensional Euler deconvolution was also performed on the upward continued aeromagnetic data using standard Euler deconvolution (Figure 9). This was basically carried out so as to locate depths to the geological structures on the gridded map. The best clustering solution was gotten using a structural index of 1 (for

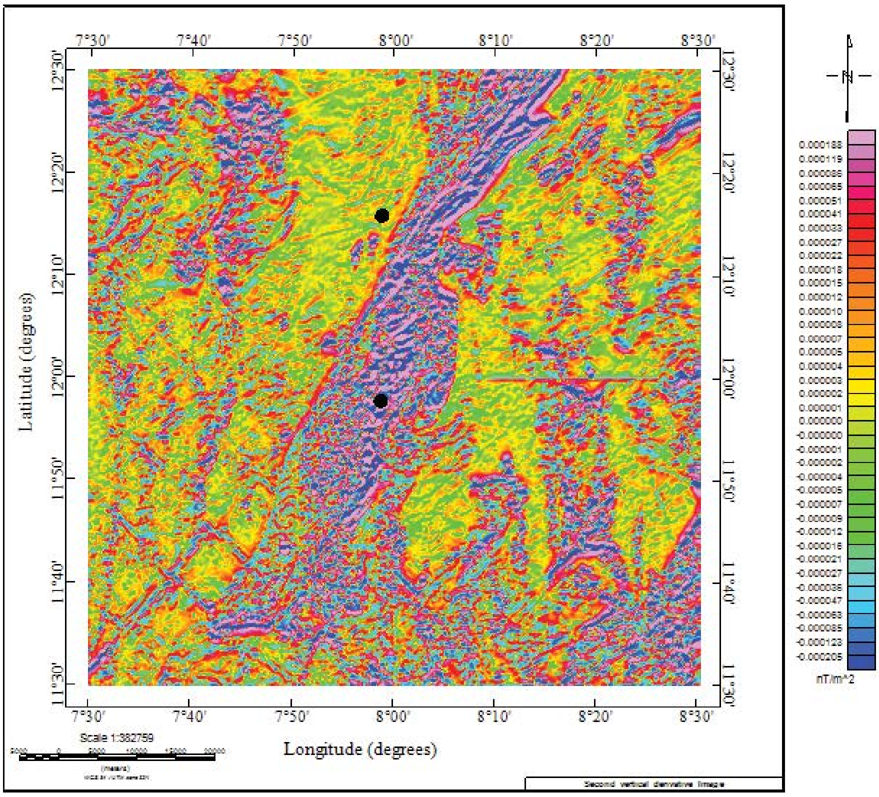

Figure 7: The second vertical derivative map, with the black points indicating the study area.

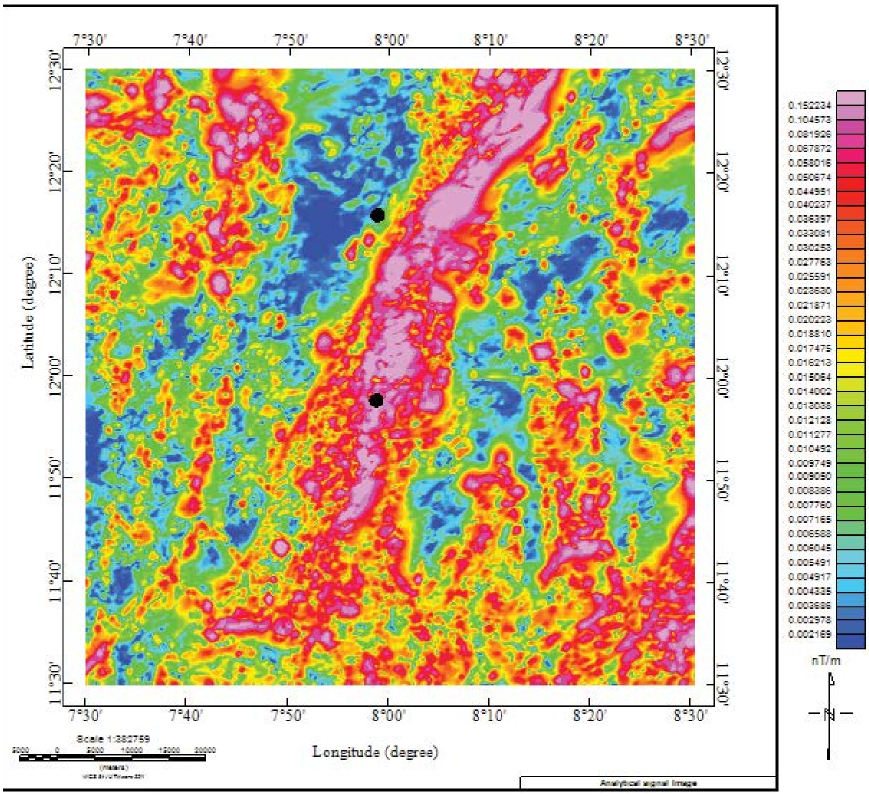

Figure 8: Analytical signal map, showing low amplitude of analytical signal around the lineaments of interest.

dike) and 9% depth tolerance for fewer solutions (i.e. the most likely solution). Structural Index 1.0, which represents cylindrical shaped body, was chosen because magnetic field of alkaline intrusions can simply and accurately be inferred with cylindrical shaped body. The dike model depth solution could be attributed to a fracture which is filled by the material. This material is suspected to be a Gold mineral within the fracture. The results were plotted on the upward continued shaded relief map for effective correlation.

Lineament map was created (Figures 10 and 11), showing the long trends which controls the subsurface structure beneath the study area. In this study, the NE, SW and E-W trends are the dominant trends affecting the area. The lineament map was superimposed on the first vertical derivative map, to clearly show the lineament trends and also the structures in and around the mining sites.

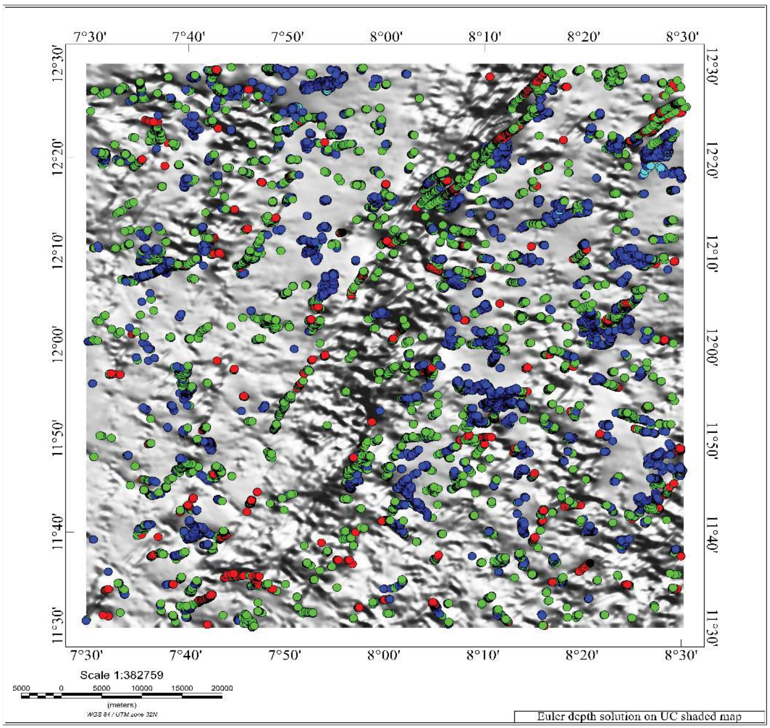

Figure 9: Plot of Euler depth solution on the upward continued shaded relief map.

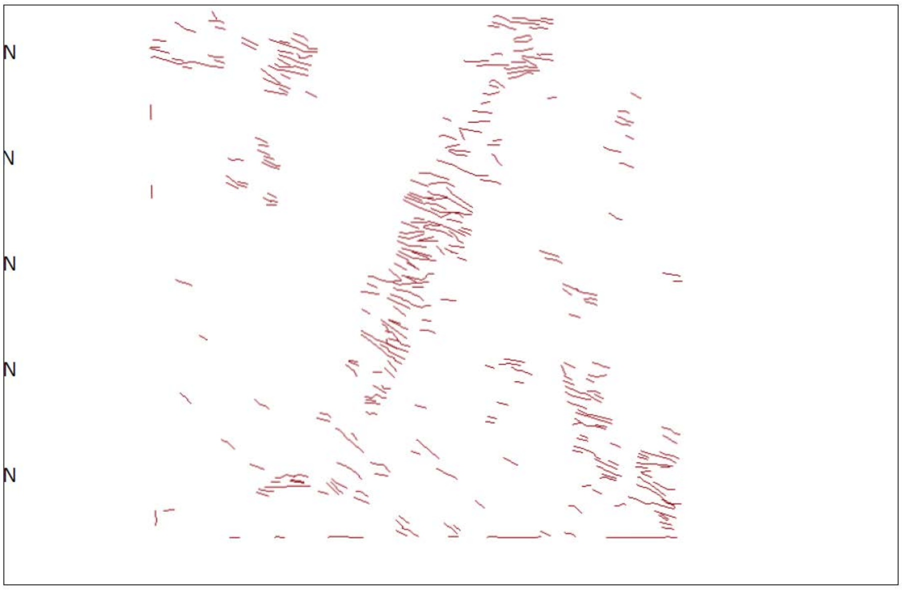

Figure 10: Aeromagnetic lineament map of the study area.

DISCUSSION

In this research work, an aeromagnetic geophysical technique was utilized to delineate and characterize subsurface geologic structures in and around the study area. These structures are trending NW-SE direction. Residual gravity anomaly, upward continued map, first/second VD maps and analytical signal map derived from aeromagnetic data characterized the subsurface geologic structures.

The residual magnetic intensity image shows high magnetic susceptible areas in low magnetic values, while less magnetic susceptible areas are depicted as high magnetic values. By removing the regional magnetic anomaly from the measured anomaly, both the negative and positive residual magnetic intensity values were obtained. The residual magnetic intensity level in the study area ranges from 81.9 to 114.0 nT.

The residual magnetic intensity map was upward continued to 250 m. In physical terms, as the continuation distance is increased, the effects of smaller, narrower and thinner magnetic bodies progressively disappear relative to the effects of larger magnetic bodies of considerable depth extent. As a result, upward-continuation maps give the indications of the main tectonic and crustal blocks in an area. The upward continued grid shows a smoother surface, hence the upward continuation helped to remove noise from the residual data before carrying out other enhancement techniques.

To observe the near-surface source magnetic features that are associated with geological structures, the first vertical derivative (FVD) filter was applied on the upward continued grid. The colour vertical gradient image of the residual magnetic intensity enhanced

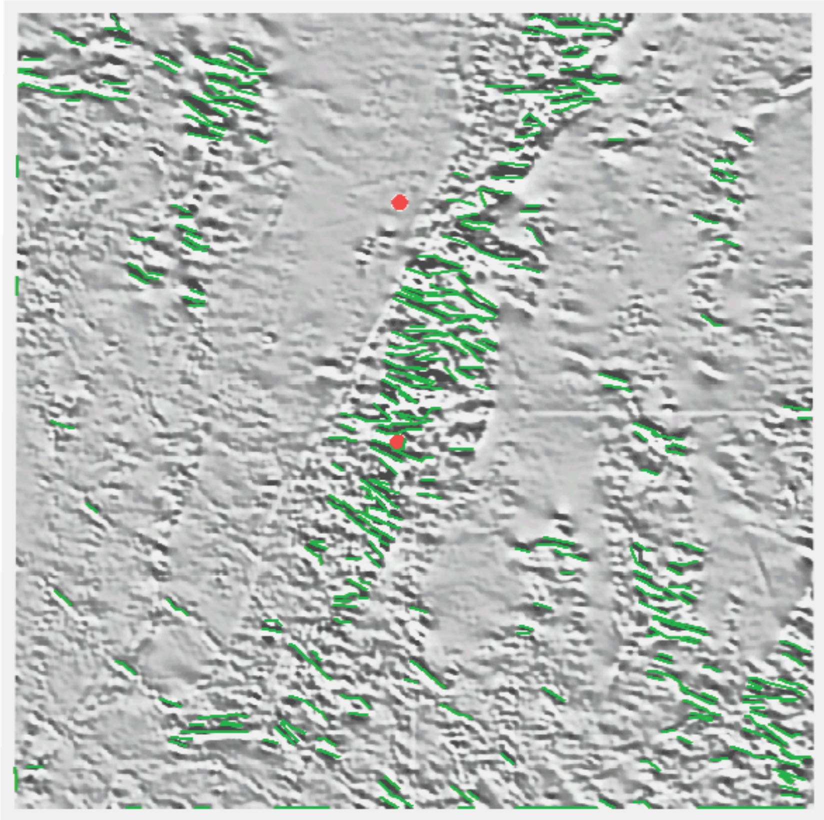

Figure 11: Aeromagnetic lineament map of the first vertical derivative.

the image by showing major structural and lithological detail which were not obvious in the upward continued image. The first vertical derivative also shows linear structures (lineament) across the study area with one passing through the mapped gold mining area and hence may have acted as a conduit through which the gold mineralization flow.

Second vertical derivative calculations were performed on the aeromagnetic data. The second vertical derivative analysis provides a means of discriminating local features while suppressing broad and regional structures. This filter has a better resolving power than the first vertical derivative and derivative maps can, therefore, be used to sharpen the edges of magnetic anomalies and to better their locations.

To know the source positions of the magnetic anomaly regardless of direction and remnant magnetization in the sources, the analytical signal filter was applied to the upward continued grid. The result indicates the amplitude values ranging from 0.02169 nT/m to 0.15223 nT/m. The zone suspected to be fault zone has low magnetic susceptibility values ranging from 0.002549 SI to 1.654578 SI. This could be attributed to the mineralization of gold discovered in the study area. The delineated linear structure (NE–SE trends) suspected to have acted as a conduit through which gold mineralization flows and deposit in the study area, occupies an area of low amplitude of analytical signal and these agree with Gunn et al. [26], who stated that low magnetic zones are interpreted to have resulted from possible mineral deposits. Gold is among minerals considered to be very low in magnetite content. High magnetic susceptibility contrasts are also observed in other portions of the map which are possibly due to outcrops in the study area. High magnetic susceptibilities are normally found in bodies associated with basic crystalline rocks such as basalt, granite, gneiss, and schist.

Euler deconvolution technique was applied to the residual aeromagnetic data of the study area with a structural index of 1.0 in order to determine depths. The solutions obtained clustered around the region where the sources were located and this was superimposed on the shaded relief map of the second vertical derivative. It indicates that the depth ranging between 244.5 m to 1436.0 m in the NE–SE trending lineaments.

CONCLUSION

The interpreted aeromagnetic data in this research has characterized the lineament structures which pass through gold mineralization zones at Shanono local government area of Kano State and its environs. The major structural anomalies trend along NE-SW and NW-SE directions. Both qualitative (second vertical derivative and analytic signal) and quantitative (Euler deconvolutions) techniques were used in achieving the objectives of this research. Euler deconvolution solution of the aeromagnetic data also gave the depth estimate ranging from 244.5 m to 1436.0 m. The contact model produced shallow depth ranging of 101.3 m to 1495.5 m while the dike model, on the other hand, produced depth range of 435.7 m to 2411.9 m for the five selected profiles. This is because dike model anomaly occurs at a greater depth than the contact model. The contact model seems to best fit the study area since the delineated structures/lineaments of interest occur at a shallow depth. Magnetic susceptibility values range from 0.0000987 to 22.483055 SI units for the five selected profiles.

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