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ORIGINAL RESEARCH ARTICLE

Geophysical Prospecting for Mineral Potential Zones in Zamfara and Environs, Northern Nigeria Basement Complex

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ABSTRACT

The importance of mineral exploration to Nigeria's present economy cannot be overemphasised, especially in the northern states where crude oil explorations have not come to light. To aid in this quest, an investigation of subsurface structures was conducted in this study to identify and delineate potential mineralization zones in the Zamfara area of North-western Nigeria. To achieve this, aeromagnetic data were analysed and interpreted. The total magnetic field intensity (TMI) data were first reduced to the magnetic equator. Regional-residual separation was then carried out to obtain the residual field intensity map of the area, after which several qualitative enhancement techniques – first vertical derivative and analytical signal – were used to further analyse the data in the Oasis Montaj environment. The results revealed that the area's total magnetic field intensity falls within the range of -78 to +108 nT after a background field of 33,000 nT was removed. The regional magnetic field intensity trends in the NE-SW direction. Both the first vertical derivative and analytical signal indicated a cluster of anomalies in the south-eastern part of the study area, interpreted as faults, folds, contacts, and shear zones, which are indicative of mineralized zones. Source parameter imaging analysis of the data revealed that the anomalies of interest were primarily located at depths of less than 200 m.

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INTRODUCTION

Environmental degradation due to indiscriminate excavation, social disruptions, and conflicts are some of the problems associated with artisanal mining in Nigeria, particularly in Zamfara State. Non-invasive geophysical techniques, such as the magnetic method, can be applied to pinpoint areas with high mineral potential without harming the environment. Despite the larger part of Nigeria is underlain by basement rocks, which are rich in solid minerals, the search for solid minerals has not been given adequate attention by the formal sectors. Only artisanal mining, causing environmental damage and conflicts, has been taking place outside the legal and regulatory framework. Nigeria's solid mineral sector accounts for less than 1% of the country's GDP (Saalmaan, 2017). Knowledge of the structural architecture of mineralized zones, the distribution and orientation of faults, fractures, and shear zones is key to understanding mineral deposits' formation, origin, and location.

In Nigerian basement rocks, solid minerals such as gold, Tantalite, Sapphire, Silver, Iron, and Quartz are formed by the intrusion and crystallization of hydrothermal (magma) fluids within faults, fractures, and shear zones. During crystallization, the interaction of magmatic fluids with suitable wall rocks or structures results in the deposition of solid minerals (Solomon, 2004).

Solid mineral veins can be found in a variety of rock types that make up basement rock. These rocks include phyllites, quartzite, amphibolite, schists, gneiss, and granitic intrusions. This suggests that the majority of regional and local mineralization is structural, consisting of a network of Pan-African-aged faults, fractures, folds, contacts, and shear zones.

Previous geophysical studies have primarily focused on a few areas where artisanal mining activities are occurring in Zamfara State (Auguie and Ridwan, 2021; Arogundade et al., 2022), without considering the entire state or a substantial part of it.

To investigate the faults, fractures, and shear zones system of Zamfara and neighbouring areas, high-resolution aeromagnetic data were acquired and analysed to delineate areas of solid mineral deposits. Specifically, qualitative and quantitative imaging techniques were employed to locate exploration targets and identify new veins with potential mineral resources.

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METHODOLOGY

The high-resolution aeromagnetic data (resolution of 0.001 nT) for this research were acquired from the Nigerian Geological Survey Agency. Fourteen (14) $0.5^0 \times 0.5^0$ sheets were knitted together to form the composite total magnetic field intensity (TMI) map to adequately cover most parts of Zamfara State, especially the mineral potential areas. The TMI were gridded using the bi-directional gridding method, which is ideal for parallel data in order to strengthen trends perpendicular to the flight lines. Due to the bipolar nature associated with magnetic field intensity data, the TMI grid data were transformed using the reduction to the equator (RTE) filter in order to align anomalies directly over their causative bodies (GETECH, 2007). Regional-residual separation was then performed on the RTE-TMI gridded data for the area to obtain the residual field intensity map. The residual field intensity map was then processed using the first vertical derivative and analytical signal in order to reduce noise and enhance magnetic anomalies associated with the edges of geological structures.

First vertical derivative

The first vertical derivative (FVD) rather than high order vertical derivatives of the total field $F(x, y, z)$ was applied to the magnetic field intensity data of the study for the detection of lineaments only; this is in order to prevent the data's noise from overpowering the required signal (Anudu *et al.,* 2014). The method is commonly applied to total magnetic field data to enhance the physical expression of shallow geologic sources (Telford *et al.,* 2004). Additionally, it simplifies anomalous complexity, allowing for a clear view of the causative body (Bonde et al., 2019). The transformation can be noisy, as it amplifies short-wavelength anomalies (GETECH Group, 2007). The first vertical derivatives is given below:

$$FVD = \frac{\partial F(x,y,z)}{\partial z} \qquad (1)$$

Analytical signal

Both positive and negative peaks (amplitudes) are usually associated with magnetic fields (Bonde et al., 2019). This may make it difficult to determine the exact location of the causative body in a survey. Therefore, the analytical signal amplitude was applied to the magnetic field data as a filter for this function, and its derivative is independent of strike, dip, magnetic declination, inclination, and remnant magnetization. Three orthogonal gradients of the Total Magnetic Field can be used to calculate the 3D analytical signal amplitude for a specific point using:

$$|AS| = \sqrt{\left(\frac{\partial F}{\partial x}\right)^2 + \left(\frac{\partial F}{\partial y}\right)^2 + \left(\frac{\partial F}{\partial z}\right)^2} \qquad (2)$$

Where, F is the observed total magnetic field at (x, y). It is evident from Equation (9) that the technique requires the first-order vertical derivative (z) and horizontal derivatives (x, y) of the total magnetic field. The MAGMAP two-dimensional Fast Fourier Transform (2-D FFT) filters package in the Oasis Montaj software contains the required algorithms employed. The study carefully took the advantages and peculiarities of these techniques to resolve subsurface structures under complex geologic conditions. Source parameter imaging analysis was also conducted to determine the depths of magnetic sources.

RESULTS AND DISCUSSION

Figure 1 shows the study area's total magnetic field intensity (TMI) map. The map revealed a cluster of interchanging high and low magnetic field intensity anomalies in the range of -78 to +108 nT after removing a background field of 33,000 nT. The anomalies are characterised by low wavenumber (long wavelength), moderate wavenumber (medium-wavelength) and high wavenumber (short-wavelength) anomalies. High magnetic values are coloured red to pink; green to yellow are intermediate, while low magnetic values are blue. The background field is generally perceived to be uniform and moderate. Most of the observable anomalies are predominantly oriented in the northeast–southwest and east–west directions.

Figure 2 shows the reduced magnetic field intensity map to the magnetic equator, which is usually the case for magnetic data acquired at low-latitude regions. This has transformed the TMI anomaly map of the area into one with more precise directions of magnetization and ambient field. This has resulted in realigning and enhancing magnetic anomalies on the original TMI map. Hence, the reduced-to-equator total magnetic intensity (RTE-TMI) anomaly map has shown nearly centred magnetic anomalies directly over their respective causative geological bodies. There is a slight change in the range of values (-72 to +87 nT) for the magnetic anomalies from what was previously obtained for TMI after removing the constant background field of 33,000 nT.

The composite map depicted in Figure 1 shows a superposition of disturbances of noticeably different orders of magnitude. The larger features may generally show up as trends. They result from the deeper heterogeneity of the earth's crust and are called the *regional.* Superimposed on the regional field but more often disguised by them are the smaller, local disturbances which are secondary in size, termed the *residual* anomalies, which often provide direct evidence of the existence of reservoir-type structures or mineral ore bodies. The regional field emerges when these residuals are removed from the total field (Figure 3). The regional field typically trends in the NE-SW directions. This agrees with the result of Nyikwagh *et al.* (2008), who carried out a similar study in the Ube-Wulko area of southeast Akwanga within the Pan-African remobilized basement and that of Akanbi and Mangset (2011), who also identified magnetic lineaments trending in the NE-SW direction to have passed through the Naraguta area of the same basement complex. The residual magnetic field values were found to be between -105 and +55 (Figure 4).

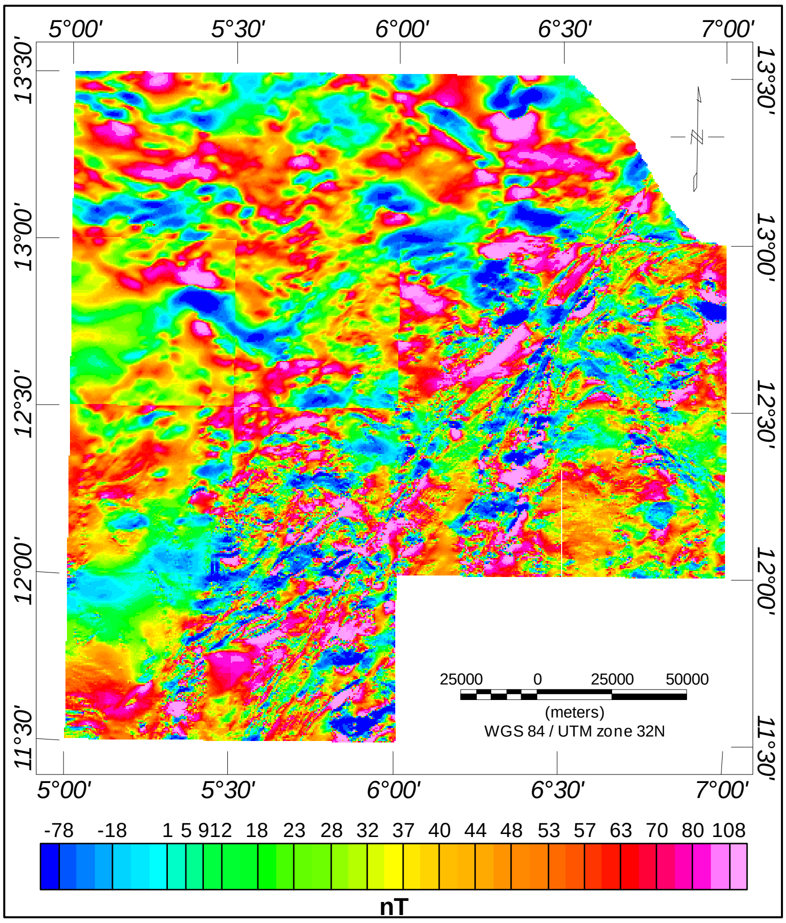

Figure 1: Total magnetic field intensity map (TMI) of the study area

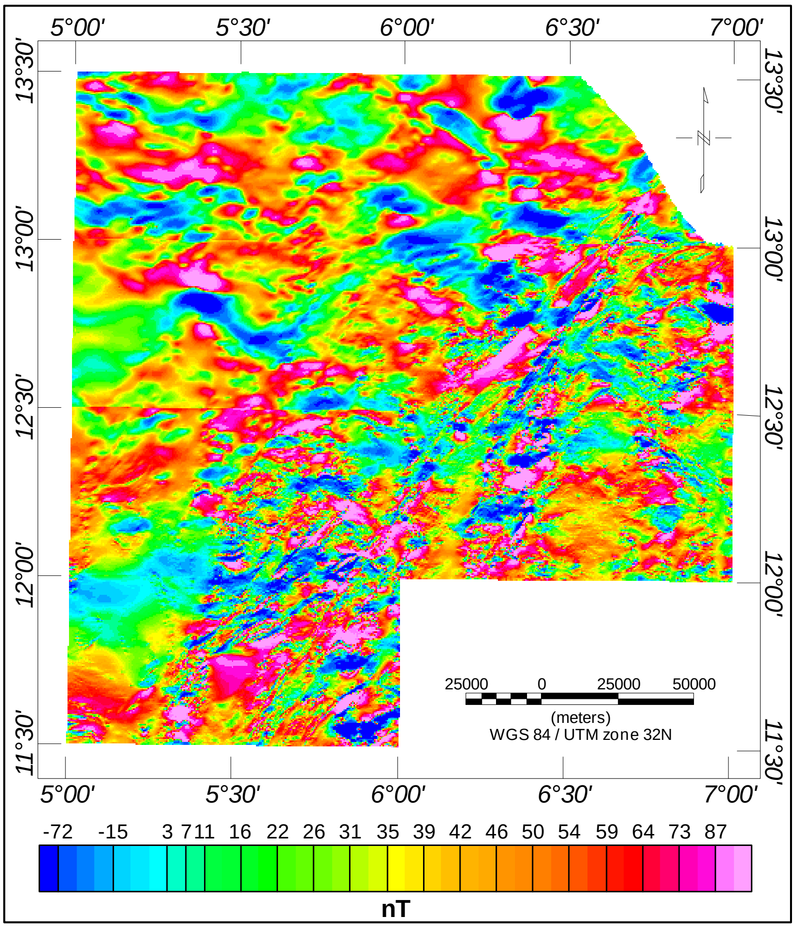

Figure 2: Reduced to equator of total magnetic field intensity (RTE-TMI) map of the area

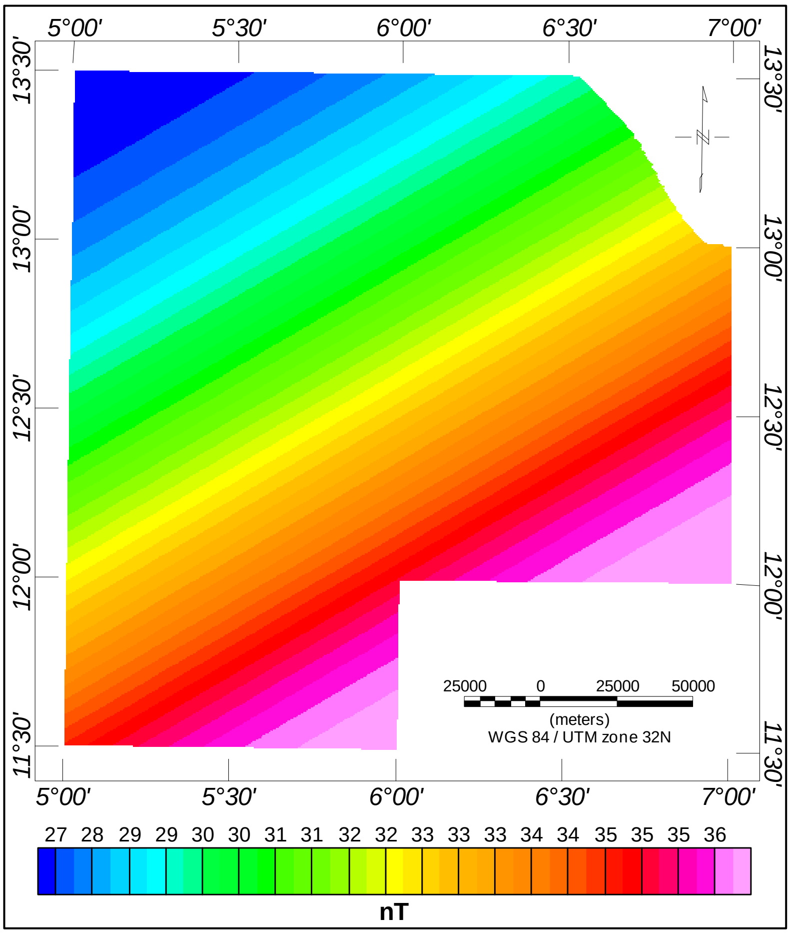

Figure 3: Regional magnetic field intensity map (RgMI) of the study area

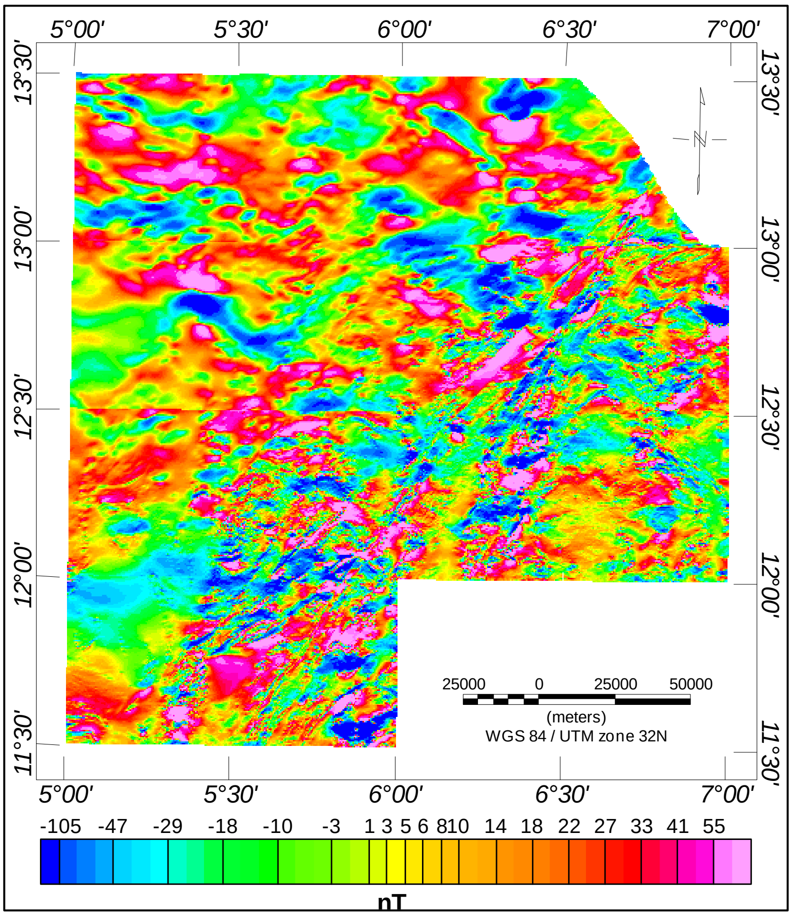

Figure 4: Residual magnetic field intensity map (RsMI) of the study area

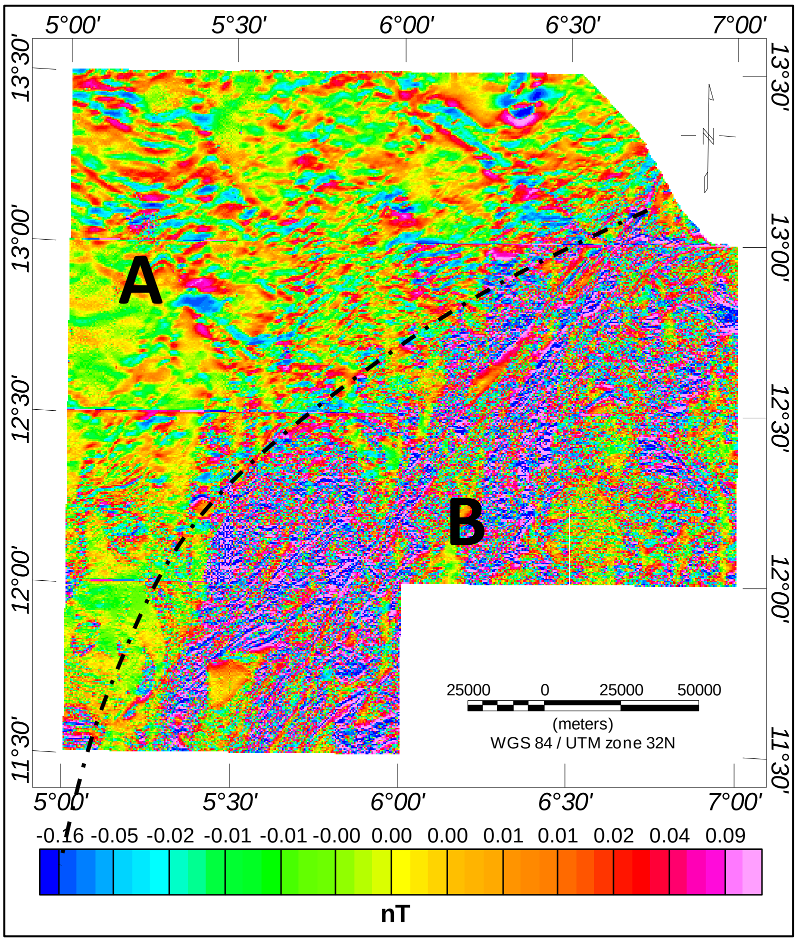

Figure 5: First vertical derivative map (FVD) of the study area

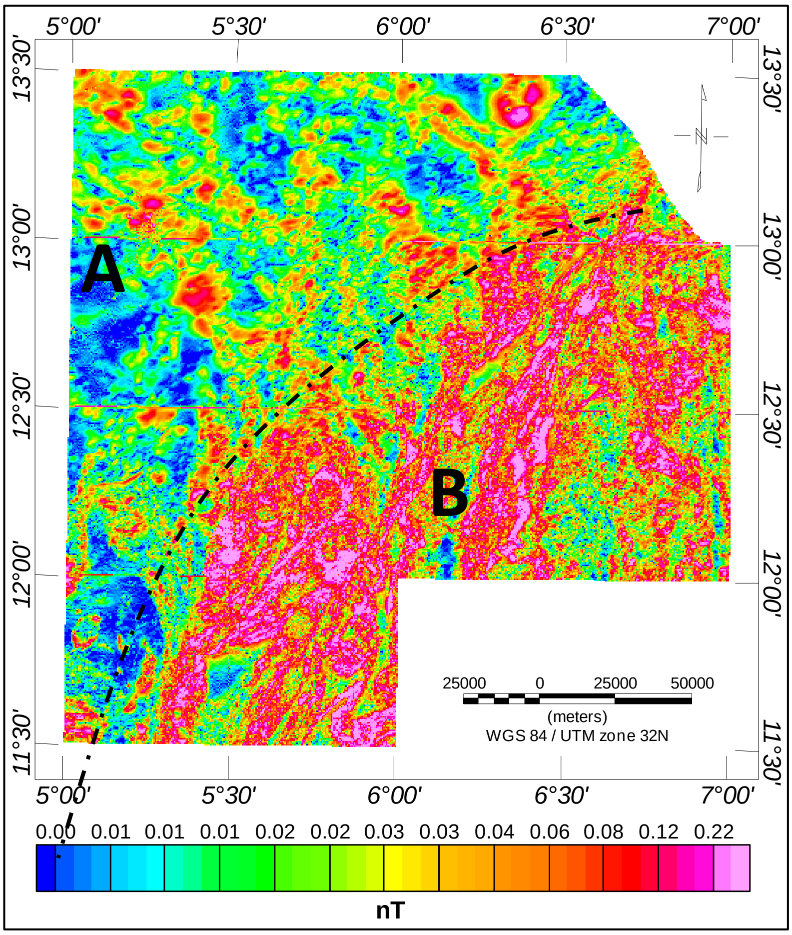

Figure 6: Analytical map (AS) of the study area

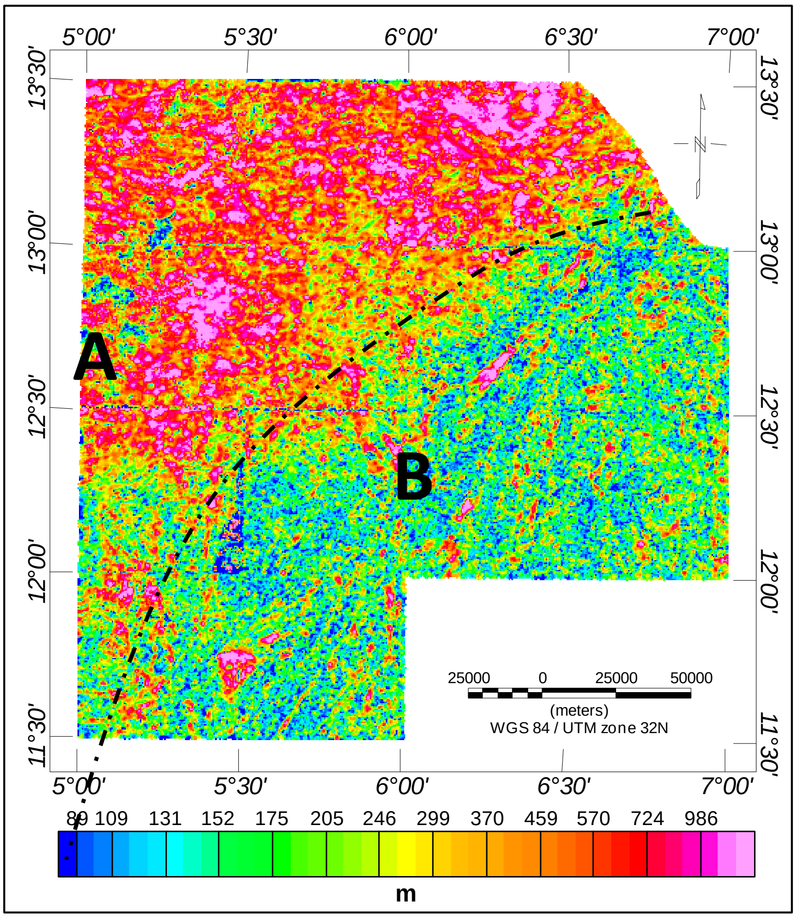

Figure 7: Source Parameter Imaging (SPI) of the study area

Figure 5 is the first vertical derivate map of the study area. Based on the figure, the area can be divided into two distinct regions, marked as A and B. Region A is characterized by near-horizontal, curved anomalies trending east-west, which are interpreted as folds. The majority of the observed magnetic lineaments in Region B are inferred to be caused by faults, contacts, and shear zones because of their linear nature. These several NE–SW trending narrow linear anomalies located around the region marked B, in the south-eastern part of the study area, are identified as dykes and faults since long, narrow features are very often due to dykes and fault strata with magnetic impregnation or long ore bodies (Anudu et al., 2014).

Comparing the first vertical derivative map (Figure 5) with the analytical signal map (Figure 6), the analytical signal does not resolve the curvilinear structures in Region A very well. What can be inferred from the region instead is an igneous intrusion with a sedimentary formation, likely the Gwandu Formation of the prominent Sokoto Basin. In Region B, both methods have shown a good correlation in resolving the geological features in the area. Comparing also with the regional map (Figure 3), region B of Figures 5 and 6 correlates well with Figure 3, as the structures revealed a trend in the NE-SW direction in conformity with the regional map.

To determine the depths of the geologic structures identified, source parameter imaging analysis was carried out and presented in Figure 7. It is observed from the figure that the depths obtained for the study area are generally below 1000 m. Region A, is predominantly of higher depths compared to B. For most part of region B, which is the area of economic interest, depths of anomalies are mostly below 200 m.

CONCLUSION

This study analysed and interpreted the aeromagnetic data maps covering Zamfara and environs, in the Northern Nigeria basement complex. Magnetic closures of both high and low sensitivity, spanning the range of -78 to +108 nT, were obtained after a background field of 33,000 nT was removed. These were connected to the presence of ore bodies in the area and regional anomalies trend in the NE-SW direction. Both the first vertical derivative and analytical signal indicated a cluster of anomalies at the southeastern part of the study area (Region B), trending in the NE-SW direction as was the case for the regional field, which is indicative of mineralized zones. Region A, located in the north-western part of the study area, has shown near horizontal curvilinear anomalies indicating a fold system as obtained from the first vertical derivative analysis; and igneous intrusions interpreted from the analytical signal. Great majority of these anomalies are located at a depth of < 200 m.

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